IRON ROOFS.

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IRON ROOFS.

EXAMPLES OF DESIGN.

DESCRIPTION,
ILLUSTRATED WITH WORKING DRAWINGS.

SECOND EDITION.

BY

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Fellow of King's College, London.

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TO

GEORGE BARCLAY BRUCE, Esq.,

PRESIDENT OF

"THE INSTITUTION OF CIVIL ENGINEERS,"

WHOSE NAME HAS FOR MORE THAN FORTY YEARS BEEN HIGHLY DISTINGUISHED IN CONNECTION WITH THE PROFESSION OF CIVIL ENGINEERING,

THE SECOND EDITION OF THIS WORK

IS

WITH PERMISSION

Respectfully Dedicated,

BY HIS FAITHFUL SERVANT,

THE AUTHOR.

PREFACE.

THE demand for a book, which would serve as a guide to the Civil Engineer, in the selection of the best class of Iron Roof, for the covering of a large or small space, where particular requirements have to be met, induced the Author to prepare the first edition of this work. His chief object was simply to provide a record of the style of design adopted in some of the best known roofs that have been erected. The second edition has been considerably enlarged and improved. Metre scales have been added to the Plates, and an Appendix inserted in the letter-press, in which the usual specified tests for material have been investigated, and the calculation of strains in some of the best known forms of roofs considered. The Author trusts that the tabular statement of the principal dimensions of fifty iron roofs on page 36, arranged in the order of their span, may prove useful. Too much importance must not be laid upon the cost quoted for different roofs, as they were erected at different times, and the price of material is constantly varying. Even with a uniform price for iron, comparisons cannot be usefully made, unless every particular is included. The Author has, however, stated the price where possible, as one of the questions which engineers are compelled to enter into, is the financial result of their work. In conclusion, the Author desires to express his gratitude to those Engineers and Contractors who have supplied him with copies of the working drawings from which the several Plates have been photo-lithographed by Messrs. Sprague & Co., and he hopes that the vastness of the subject may be sufficient excuse for the omission of any special roof that the reader might have expected to have found mentioned.

A. T. W.

WESTMINSTER,
January 1888.

ERRATA.

Page	7,	line	17, read "9 and 10" in place of "9 to 11".
,,	9,	,,	33, read "14 to 17" in place of "12 to 18".
,,	9,	,,	46, insert "18" and omit "20 A."
,,	18,	,,	28, read "46" in place of "40".
,,	19,	,,	9, read "42" in place of "41".
,,	21,	,,	10, read "29" in place of "46".
,,	26,	,,	14, insert "58" after "57".
,,	27,	,,	12, read "13" in place of "58".
,,	30,	,,	17, read "30 and 31" in place of "29 to 31".
,,	31,	,,	49, read "63" in place of "64".

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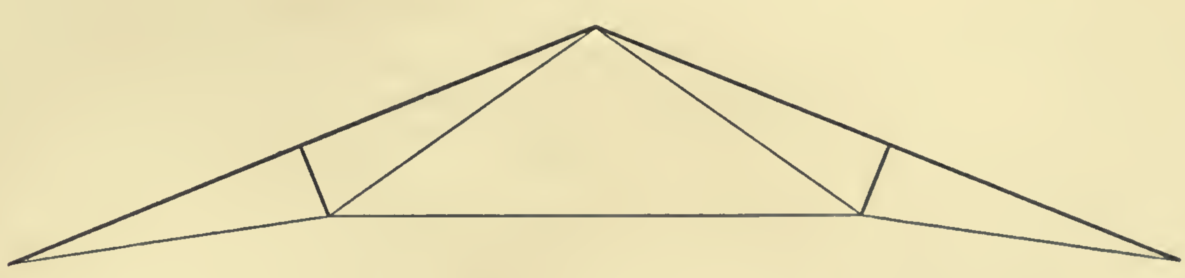
DESCRIPTION.

The subject is very extensive, but much less has been written about the design of iron roofs than of iron bridges; and the Author, having examined and collected together drawings of some of the details of various roofs for the purposes of his own study, thought that a treatise which exhibited the merits and objections of various systems of roof construction which have been adopted in different situations might be useful to Engineers for reference. His object is not to propound new theories, but simply to give a few examples of design to be found in practice, without attempting to describe minutely particular forms of covering designed to suit special cases, or to state in detail the dimensions of the framework supporting the same. The Author does not propose here to enter into the consideration of the many valuable mathematical formulæ which have already been published in various well-known works, showing how the strains in the component parts of a roof are calculated. To design an iron roof properly, it is indispensable, in order to secure efficiency combined with economy, that the strains should be accurately worked out, and not only the result arrived at considered, but the means by which that result is obtained, so as to provide for the intermediate as well as the direct action of any pressure; as it is evident, that a result applicable under any special condition of loading, may become greatly increased or reduced under any variation of a load. It is not always the total amount of strain that is required to be considered, but the manner in which it has gradually and successively accumulated in the construction, and which depends so much upon arbitrary assumptions applicable only to the special circumstances under which the roof is to be erected. The design and cost of such works depend also very much upon local circumstances, the reduction of amount of material being, in some places more than others, attended with great increase in the cost of labour, and consequently a particular type that would be economical in one situation, would be inexpedient in another. The primary characteristic or feature in the design of a roof is the main rib or principal, and it is the form of principal, whether truss or arch, which suggests the class or type that any particular roof may be distinguished by. The object of a truss is to secure

Fig. 1.



pressure upon the supports in a vertical direction only. Arches and other forms, in which the pressure is at an angle outwards with the vertical, giving to the roof what is generally called a horizontal thrust, will also be illustrated. Trusses may be best examined by comparing the bracing. Figures 1 to 12 show the different kinds which will be alluded to in the following remarks. The

thick lines in these figures represent members in compression, and the thin lines members exposed to tension. When iron was first used in the construction of a roof it was only employed for those members of wooden trusses which were subject to tension, it being so much better adapted than

Fig. 2.

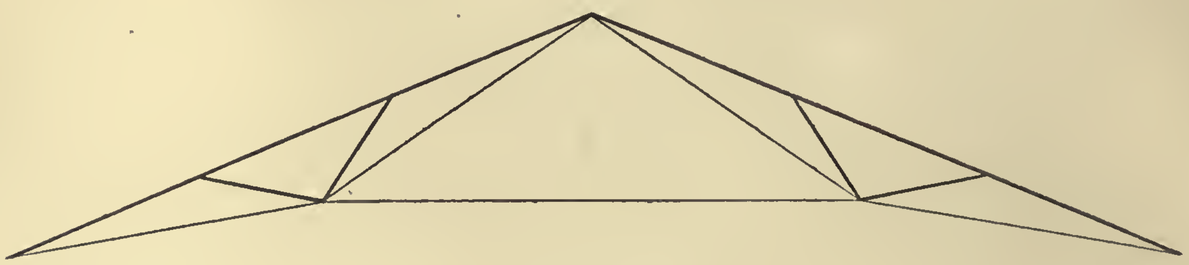


Fig. 3.

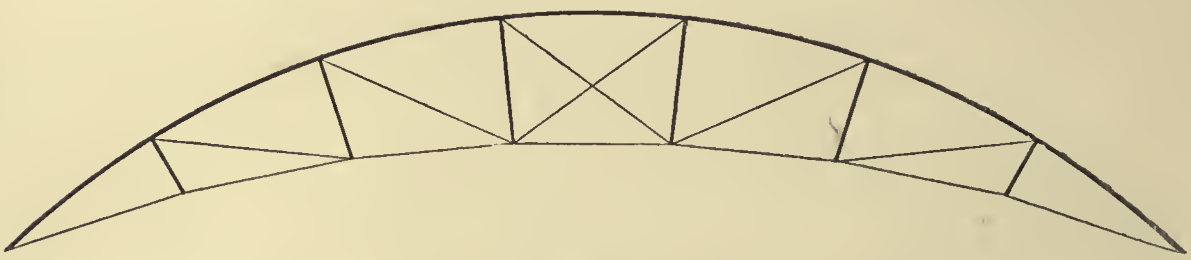
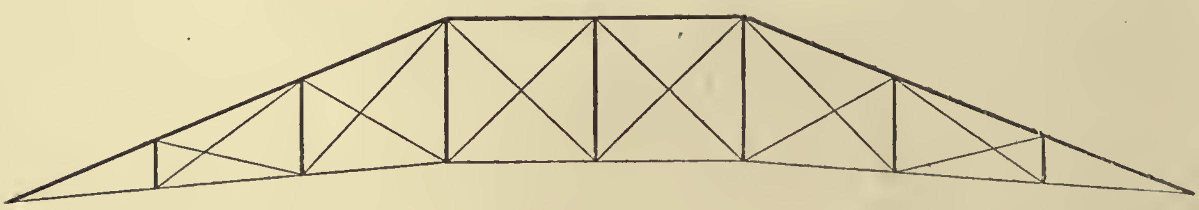


Fig. 4.



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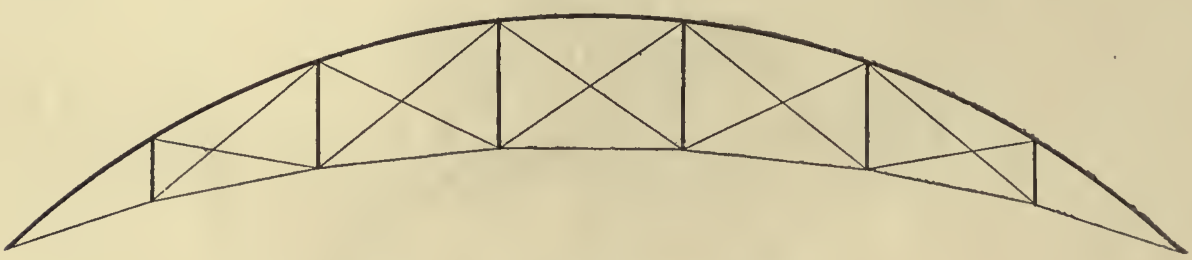

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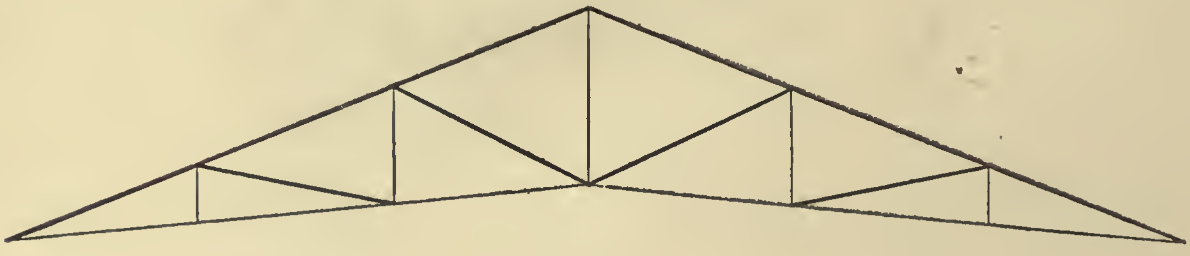

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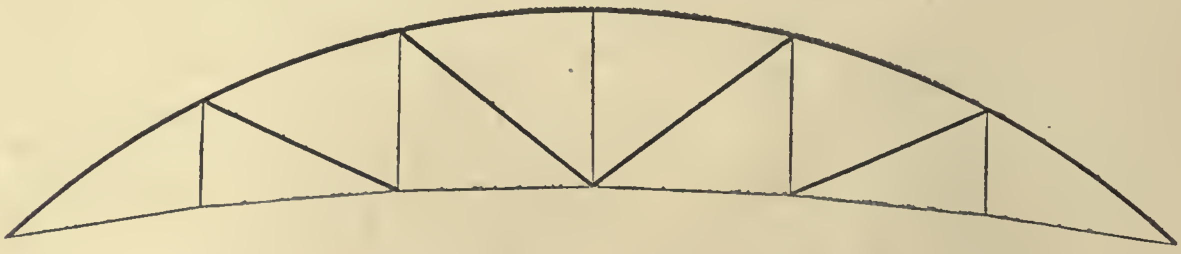


timber to resist such strain; but as the machinery for manufacturing different sections of iron improved, its use became more general, and iron was substituted first for one member of a roof, then for another, until gradually the whole of the main framework was formed of this material in

Fig. 8.

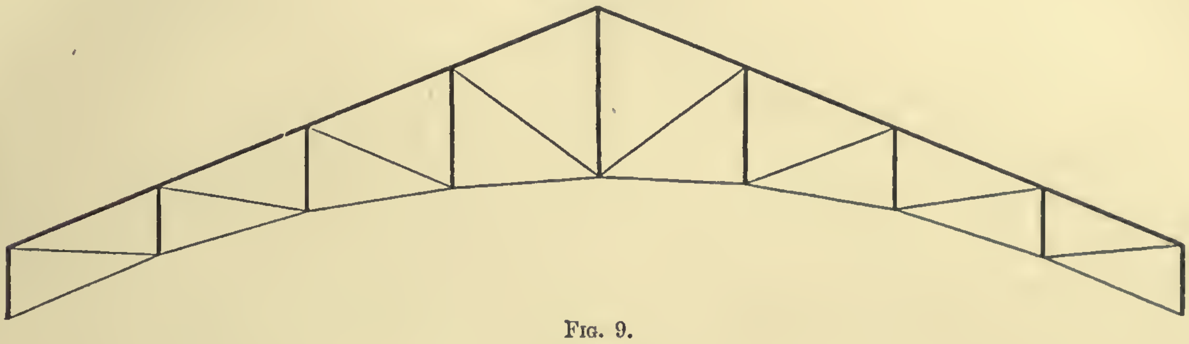


Fig. 9.

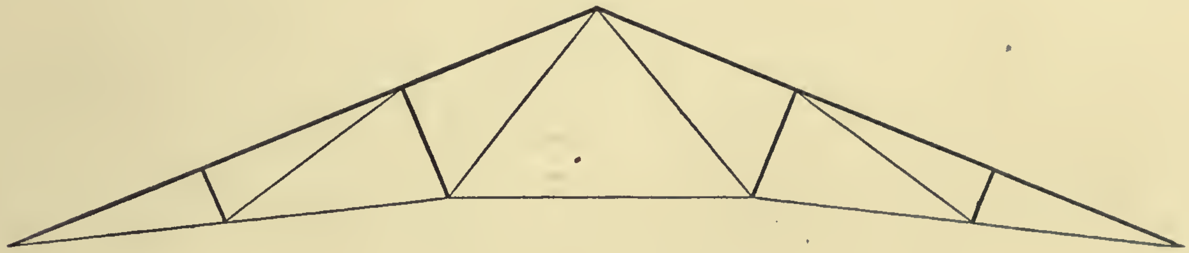
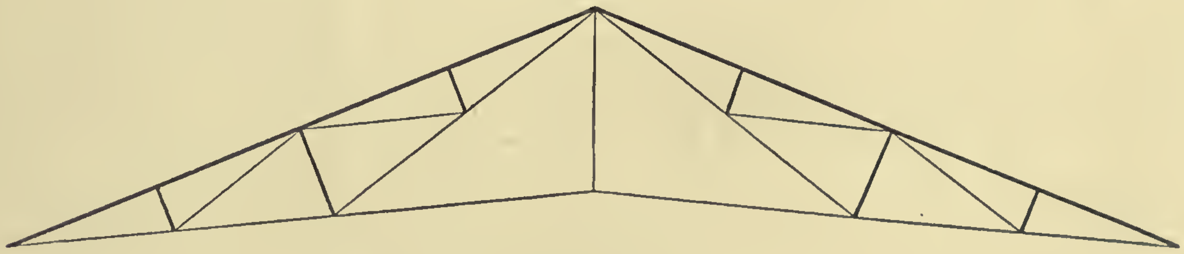


Fig. 10.



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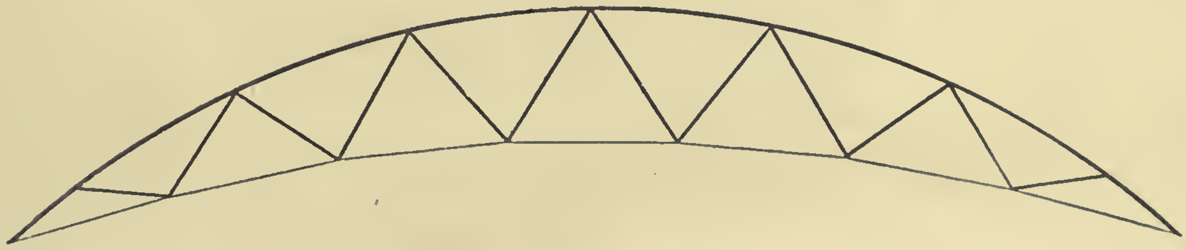
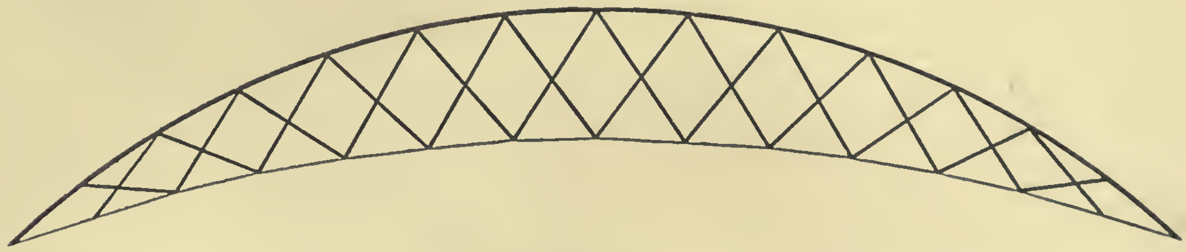


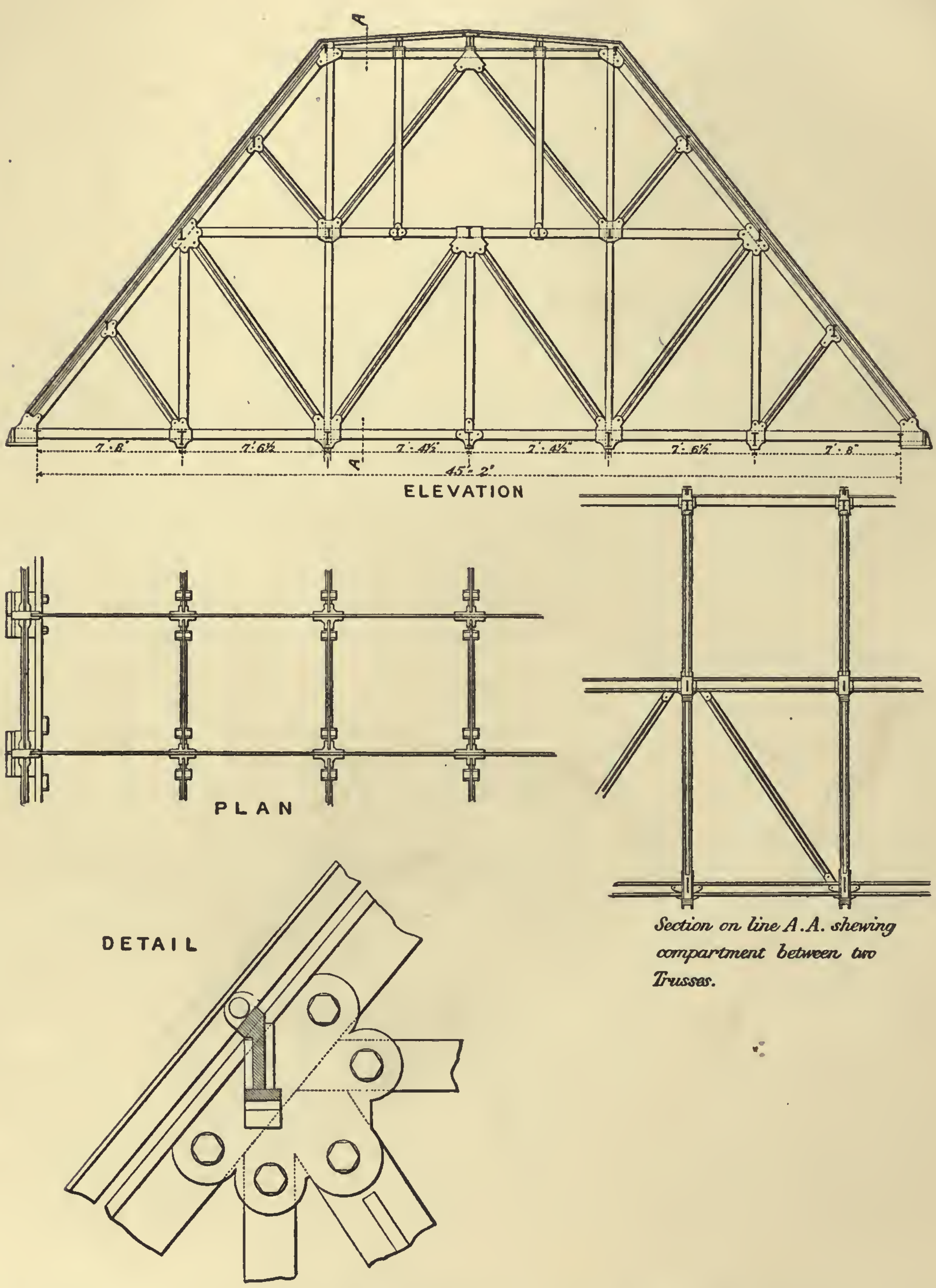
Fig. 12.



different forms. Hence we find that many of the early iron roofs closely resembled the form of construction adopted for ordinary timber trusses, the only alteration being in their section and detail of attachment at the joints. In a similar manner many iron arches of bridges resemble masonry designs, and are heavy and wasteful imitations. A comparison of the depth at the crown of arched bridges shows that the strains in ironwork are better understood than at the time when Southwark

Bridge was erected over the river Thames. In Westminster Bridge, a curve parallel to an ellipse was adopted as giving better headway than a true ellipse. An elliptical curve, however, is not the most economical construction for ironwork. The principal of the trussing of the roof over the House of Lords (Figure 13) was a great advance upon the old systems that had been adopted, but would probably be much modified if constructed in the present day.

Fig. 13.

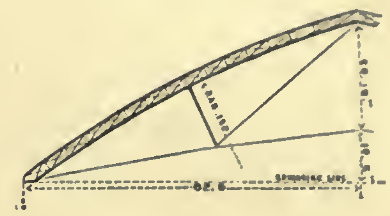


The introduction of struts in a braced framework is with the object of reducing to a minimum the transverse stress that would otherwise be induced upon the members under strain. Figure 1, which was introduced during the early days of railway construction, is still within certain limits one of the simplest and best forms. The central strut supporting each rafter is held in position by the tie-rods which connect the head with the extremities of the rafter, and the

horizontal thrust upon the supports is taken up by the tie-rod which connects the two struts and holds the trussed rafters together.

A useful and economical adaptation of the type of truss shown in Figure 1 is to be found in the Bristol Joint-line Station roof, designed by Mr. Francis Fox, of Temple Meads, Bristol, where the rafters are of a segmental form meeting at an apex in the centre, forming a rigid arch of 125 feet span, with a rise from springing level of 31 feet 3 inches, or one-fourth of the span (see Figure 14). Owing to the form of the roof and its considerable rise the side walls could be kept low, and some saving in masonry was thus effected. They are carried up 24 feet above the platform at the springing level, or less than one-fifth of the span. The circumstances of the site did not admit of any design which would exert an outward thrust upon exterior buttresses, hence tie-rods at the springing level were indispensable. The tie-rod rises in the centre 10 feet 5 inches above the springing. There are twenty-six principals, including two gables of ornamental design dividing the roof into 25 spaces at an average distance of 18 feet 9 inches apart. The purlins are of wrought-iron lattice arch construction, with horizontal bearing on top for the glazing, which follows the slope of the roof, and is raised at intervals on standards for ventilation. The roof is curved in plan, having a radius of 1000 feet along the outer wall, and a length of 500 feet measured along the platform wall. No special provision was considered necessary with this form of construction for any play in the shoes into which the feet of the principals are secured. The principals if loaded equally are without transverse strain, but in order to provide against the effect of wind on one side or of unequal loading, as well as for the sake of appearance and the support of the heavy tie-rod, some light suspension-rods are added. The pointed form of principal was adopted chiefly because it harmonised with the general architectural character of the station buildings, and because some kind of curve in the principal appeared almost necessary for satisfactory effect in the case of a roof on a somewhat sharp curve. The price of iron was high at the time of the letting of the contract, and the roof cost 37*l.* 16*s.* per square of 100 feet measured on plan, including glazing and slates on boarding with all extras. The price was increased by the fact that the roof was built on a curve, and that in consequence the purlins varied in length (see Plates Nos. 1 to 4). The roof could, no doubt, be constructed for a less sum now.

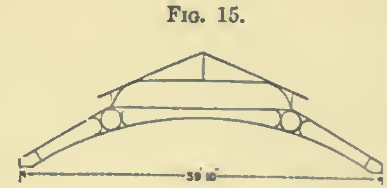
Fig. 14.



The High Level Station on the London Chatham and Dover Railway adjoining the Crystal Palace, Sydenham, is an example of a roof of the same width as the Bristol Station, divided into two spans of 62 feet 6 inches each. The type of truss adopted is also similar to that shown in Figure 1, consisting of upper segmental lattice ribs, having a total rise of 17 feet above the springing level, and rise of tie-rod in the centre 9 feet, forming a principal 8 feet in depth. The principals in each span divide the roof into 26 spaces, connected by five lattice purlins in each bay, and are placed 20 feet 6 inches apart, giving a total length of 533 feet.

The roof over the Blythwoodholme Arcade, Glasgow (see Figure 15), is an example of a space of about forty feet wide, covered with an arched form of construction.

Fig. 15.



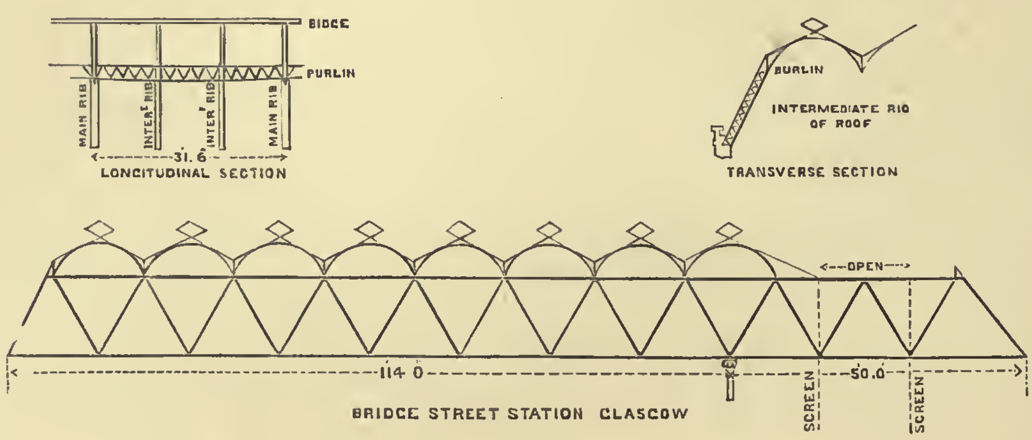
The member which has the greatest influence upon the strains in a roof is the tie-rod. The result of raising it in the centre above the level of the points of support is to reduce the strength of the truss due to its diminished depth, or practically to throw more strain upon the component members of the roof, but additional headway is gained and a better general appearance presented. It is obvious that the greater the rise or angle of inclination of a rafter to the horizon, the greater will be the weight and area of the covering, and consequently the cost will be increased. The cheaper descriptions of covering, such as slates and tiles, require a steeper pitch than the more expensive coverings of glass or zinc. A good pitch for a roof with straight rafters is 1 in $2\frac{1}{2}$, giving a rise of principal equal to one-fifth of the span.

It is an essential feature in connection with the economy of all structures that the number of

different parts should be as few as possible; but with spans of over 30 feet, if the top rib of the rafter be not constructed as in example Figure 1 its length becomes such that more than one strut is necessary, and the rafter is supported at two intermediate points as in Figure 2 of the same class, which may be adopted for spans up to 40 feet. Examples of Figure 2 may be seen in the covered way over the approach to the Victoria Station, where the trusses are placed at moderate distances apart, and supported on the bottom flange of transverse girders spanning the width of the railway. Other examples of longitudinal roof trusses carried on the bottom flange of transverse girders, may be seen at the Kentish Town and Camden Road Stations on the Metropolitan branch of the Midland Railway, where the girders are placed 21 feet 6 inches apart, and also in the side spans of the London Brighton and South Coast Railway Company's Station at London Bridge.

The roof of the Great Exhibition of 1851 also was supported on overhead girders of convenient length, with ridge and furrow covering. This method has been adopted on a large scale in the Bridge Street Station, Glasgow, which is divided into two spans of 114 feet and 49 feet respectively (see Figure 16). The large span covers the joint-line terminus of the Glasgow and South-Western

Fig. 16.

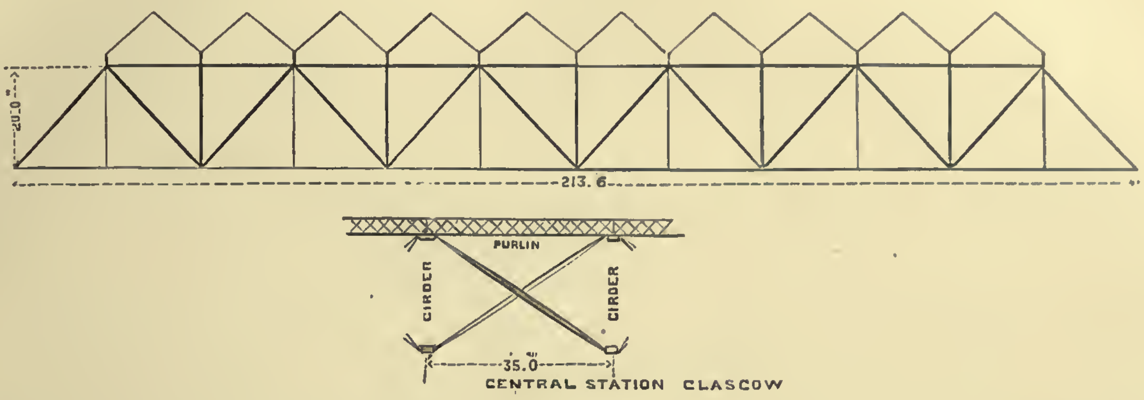


Railway and of the Wemyss Bay Railway, the latter of which is worked by the Caledonian Railway Company. The smaller side span is over the main-line station of the Caledonian Railway, which is continued across the river Clyde into the Central Station or Northern Terminus (see Plates Nos. 5 and 6). The joint-line station is covered by eight ridge and furrow roofs of small span, running longitudinally, carried on parallel lattice girders, which are supported on transverse warren girders and trussed longitudinally with three sets of vertical angle-iron bracing, uniting the upper side of the bottom flange of the transverse girders with the under side of the centre of the bottom flange of the longitudinal girders upon which the gutters rest. The ridge and furrow roofs are crowned by lanterns with louvres for ventilation. The main transverse girders are about 12 feet deep, and are continuous over both stations; they are nineteen in number and 31 feet 6 inches apart, the end transverse girder being filled in as a gable screen. The roof over the side span is open overhead for a width of about 21 feet transversely over the double line of rails from end to end of the station, the uncovered being divided from the covered portion by flat longitudinal vertical screens to shelter the platforms. To allow of contraction and expansion on the main girders, oblong holes are cut in joint cover plates of the upper boom, the lower boom being fixed to the columns. The two spans are separated from each other by a row of columns supporting the main transverse girders. The cost of the ironwork only, in this roof, was 16*l.* per square, and for iron and covering complete 22*l.* 5*s.* per square of 100 feet.

The roof over the Central Station of the Caledonian Railway Company in Gordon Street, Glasgow, is somewhat similar in construction (see Figure 17). The covering consists of ten ridge and furrow roofs of small span running longitudinally, and carried on seventeen main transverse girders, which span the whole width of the station. The total length of this roof is 560 feet, and the distance from centre to centre of supporting walls 213 feet 6 inches; the main girders are 20 feet deep, of zigzag lattice work, braced longitudinally with four sets of vertical

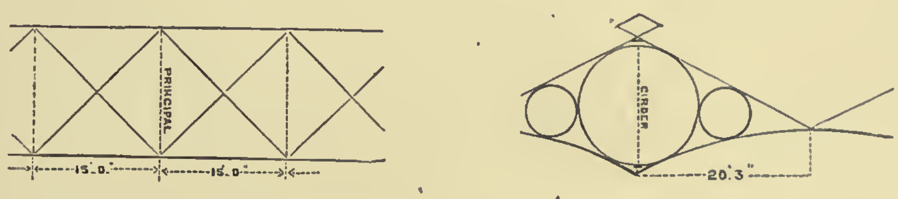
diagonals in each bay, and horizontal lattice girders carrying the gutters. The end transverse girder is filled in with wood and glass to serve as a wind screen (see Plates Nos. 7 and 8). The cost of the ironwork was 14*l.* 5*s.* per square, and for iron and covering complete 28*l.* 17*s.* 6*d.* per square of 100 feet.

Fig. 17.



The roof over the Citadel Station at Carlisle (see Figure 18) is likewise carried by transverse girders, but here the ridge and furrow covering runs parallel with the supporting girders, advantage being taken of the longitudinal diagonal bracing between these girders to carry the slopes of the roofing. The station is divided into two spans by columns placed about 40 feet

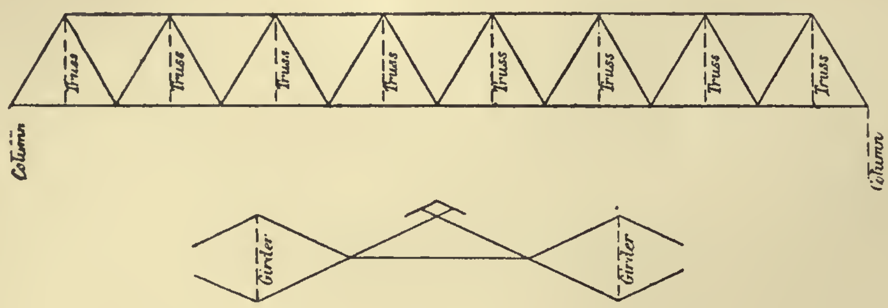
Fig. 18.



6 inches apart longitudinally. There are twenty-four transverse girders between the gables, dividing the roof into twenty-five bays. These girders are not continuous over the station but rest at one end on the side walls, their other ends meeting over the central columns. They are 15 feet deep, of single lattice pattern, which serves as transverse diagonal bracing between the roof trusses. These trusses are formed of light ornamental open cantilevers placed 15 feet apart and united in the centre between two girders supporting the gutters which run in a transverse direction across the station at a level of about 9 feet below the top flange of the main girders, the glazing being carried down to meet the gutters, while the ridge is supported on the top flange of these girders and raised to provide open side spaces for ventilation (see Plates Nos. 9 to 11). Owing to the irregular width of the station, the main transverse girders are of varying length, their maximum lengths being 128 feet 3 inches and 154 feet 6 inches respectively. Where an irregular plot of ground has to be covered, it is better to confine the irregularities to as few points as possible, letting the greater portion of the structure be composed of rectangular or other uniform figures, than to provide for the irregularities by altering the dimensions of numerous parts gradually throughout the construction. The cost of the ironwork in the Carlisle Station roof was 28,850*l.* including columns, or about 12*l.* per square. The roof over the Oban Station of the Callander and Oban Railway is carried on girders of zigzag pattern 7 feet 10 inches deep, and 71 feet 6 inches span. They are placed at distances of 30 feet apart, and divide the roof into nine bays or spaces, the total length being 270 feet. These girders carry the ridge and furrow covering in a somewhat similar manner to the arrangement at the Carlisle Station; but in the Oban roof there is an intermediate ridge and two gutters between the transverse girders as shown in Figure 19, the central portion of 15 feet span, forming the top of an A truss carried by these gutters, which are supported by open cantilevers attached to the main girders. The cost of the ironwork, including cast-iron supporting columns, was 2250*l.*, or about 11*l.* 13*s.* per square. The engineer was Mr. John Strain of Glasgow.

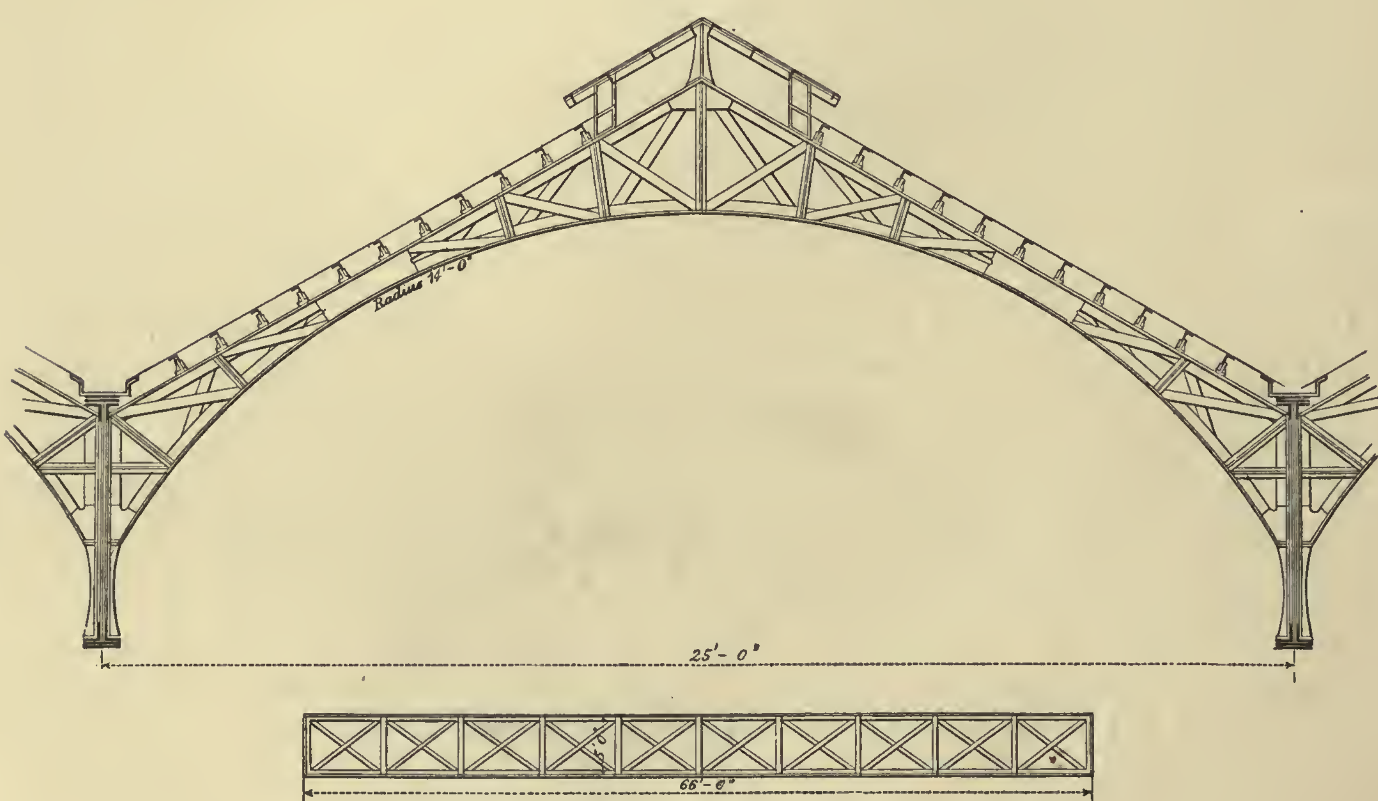
The roof over the retort-house of the Tunbridge Wells Gasworks, designed by Mr. R. P. Spice, consists of eight ranges or spans supported on transverse wrought-iron lattice girders of 65 feet

Fig. 19.



span and 5 feet deep (see Figure 20). They are placed 25 feet apart from centre to centre longitudinally. Each span between the supporting longitudinal side walls of the building is divided into ten spaces, and the roof is carried by six main principals and five intermediate principals placed alternately and connected by purlins and wind-ties. The main principals consist of straight inclined top flanges, with a curved lower flange struck to a radius of 14 feet having a rise of 7 feet above

Fig. 20.



the springing. They are 2 feet 8 inches deep in the centre, and 3 feet deep at the springing, where they are attached to verticals in the girders, and are of lattice construction, the intermediate principals being formed of T iron. This form of principal is applicable to much wider spans than that here described.

The details of the ironwork in the Paris Exhibition of 1878 were well worked out, and were designed by the late M. de Dion, President of the Société des Ingénieurs Civils. The sites selected were those of the Champ de Mars and the Trocadero. The roofs over the industrial halls were each of the class shown in Figure 1, with principals 82 feet span, placed 16 feet 4 inches apart. This form of truss and its adaptation to wide spans, as shown in Figure 10, is peculiar to iron roofs as distinguished from timber trusses, and represents the type almost universally adopted in

France. The chief stations in Paris—the Gare du Nord, de l'Est, and d'Orleans—have principals of this type; the effect of the latter roof being very good. The system is light, and comparatively inexpensive. The span of the roof over each of the machinery halls in the Paris Exhibition was 116 feet 9 inches from centre to centre of supporting columns. The trusses were placed 49 feet apart, and resemble the class shown in Figure 8, consisting of a straight upper and curved lower flange, connected by a system of bracing dividing it into eighteen panels, the inner flange springing from a bracket of the supporting column vertically for a distance of about 7 feet, whence it was curved towards the centre with the following radii: 24 feet, 49 feet 2 inches, and 119 feet 9 inches; the total rise from springing of the truss to the centre being 45 feet. In the connection of the purlins to the roof principals, allowance for expansion was provided for, by making the bolt holes at one end, attached to the bracket on the roof principals, oblong instead of circular. The grand Vestibule in the Champ de Mars building was formed by a semicircular arch, enclosing a flat screen, above which rested a central dome, forming the chief architectural feature of the construction.

The roof over St. David's Station, Exeter, erected about twenty years ago, is composed of trussed principals of the type of construction shown in Figure 10. The details were designed by Mr. Francis Fox. The length of the passenger roof at Exeter is 360 feet, with principals 15 feet apart (centres) of 132 feet span, having a total rise of 22 feet, equal to one-sixth of the span. The principals are formed of rolled iron beams, fished with double fish-plates at their junctions, which occur at the place of the three tube struts in each half principal. The tie-rod is raised 5 feet above the springing level, giving a depth of truss of 17 feet. This mode of construction is simple, but as rolled beams are deficient in lateral stiffness, some parts of the roof, especially the glazed part, were stiffened by the addition of $\frac{1}{4}$-inch plates riveted to the top flange of the principal. The principals of the two outside bays at each end of the roof were also firmly tied together by angle-iron bracing. The purlins are of timber, trussed with light iron rods, and placed about 4 feet apart. The roof was covered with diagonal boarding, upon which was laid Croggon's asphalted felt, and slated. This kind of roof was somewhat difficult of erection, owing to the considerable span and the absence of lateral stiffness in the section, but when once erected it was perfectly stiff. There are wind-ties throughout the roof, which, with the help of the diagonal boarding from purlin to purlin, keep the roof rigid. The ends of the roof are formed of wrought ironwork of ornamental design, supported by a trellis girder, which is also supported towards the middle of its span by cast-iron columns and a screen in the middle platform. The cost of the roof was about 16*l.* 10*s.* per square (see Plates Nos. 12 to 18).

An example of Figure 10, with a curved rafter, is found in the form of principal adopted at the Penzance Station of the Great Western Railway. The roof is about 250 feet long, and is divided into sixteen spaces by principals placed 15 feet $7\frac{1}{2}$ inches apart. The radius of the top flange of the principals is 68 feet 8 inches. The span of the roof is 77 feet, with a depth of truss equal to 10 feet 6 inches (centres), and rise of centre of tie-bar 2 feet above the springing level. The principals are connected by lattice purlins. There is no roller bearing, but a cast-iron bed-plate, having the surfaces in contact planed, is adopted, as the calculated expansion would be roughly only $\frac{3}{8}$ inch in length, which it is assumed the roof would be able to draw into itself in the case of contraction and *vice versâ*. This form of roof was adopted as the best to resist the strong winds which sometimes do considerable damage in the district, and the members forming the truss are attached together with riveted joints, which were preferred to bolt connections. The cost of the ironwork was 1700*l.*, or about 9*l.* per square, and the total cost, including covering of zinc on boarding with glass, was 3000*l.* (see Plates Nos. 19 and 20, and 20A).

The roof covering the Ealing Broadway Station of the Metropolitan District Railway, designed by Mr. John W. Barry, is formed of principals similar to Figure 10, but with the struts fixed vertically (see Figure 27), it being considered that the fixed load and weight of snow act vertically. The roof is in a single span of 62 feet, with a depth of truss equal to 14 feet, and the principals are placed 21 feet apart, connected by vertical purlins forming a roof 231 feet long. One end is closed with a gable screen carried by two horizontal girders, one at the springing level and the

other between this level and the ridge, while the other end of the station is closed by the booking offices.

Figure 6 shows a type of truss with inclined struts and vertical ties deduced from the queen-post truss, and is known as a queen-rod roof, the term "queen rod" being usually applied to the suspending rods analogous to princesses in wooden roofs. The roofs over the Euston Station of the London and North-Western Railway are of this form, in spans varying from 26 feet 6 inches to 62 feet 6 inches; and the same type has been adopted in the roof over their station at Bletchley, in spans of about 40 feet. The old Tithebarn Street roof of the Lancashire and Yorkshire Railway at Liverpool was constructed of this type in one span of 132 feet. The roof over the retort-house of the Dublin Gasworks, to which Mr. Jabez Church is consulting engineer, is carried by principals of this type—(Figure 6). The principals are 64 feet 3 inches span, placed about 6 feet 6 inches apart, and the feet of each rafter abut into cast-iron shoes, to which the tie-rod is fastened. The depth of the truss is 28 feet, and the rise of the tie-bar 5 feet above the springing. The oblique struts and vertical ties or suspending pieces have jaws or forks at their upper ends, where they are hung from the rafters by means of pins and screws, and at their lower ends, where they are connected with the struts and with the tie-bar by means of pinching nuts. The length of the roof is 296 feet 1 inch between end walls (see Plate No. 21). Another example of Figure 6 is to be found in the Swansea Station of the London and North-Western Railway, where the total width of 70 feet is divided into two spans, one of 64 feet 6 inches, and a side span of 5 feet 6 inches, the roof over the main span being composed of twenty-three principals 15 feet deep in the centre, with the tie-rod raised 1 foot above the springing, and placed 20 feet apart. The purlins connecting the rafters are formed of wood, with a flitch-plate on each side, and about 6 feet apart. The roof was designed by Mr. H. M. Bradford. The cost of the ironwork was a little over 1500*l.*, or about 5*l.* per square (see Plates Nos. 22 and 23). This form of construction was also used in the roof over the Great Northern Railway Station at Leeds, in two spans of 60 feet each, meeting in the centre on spandrel girders supported by columns 20 feet apart. The roof is about 300 feet long, and the principals are placed about 6 feet 8 inches apart. The same type of truss has been adopted for the principals of the roof forming the Joint Committee's General Station at Perth, which is divided into two spans of 57 feet 6 inches each, meeting over a central row of columns. The principals are each divided into six bays and are placed 8 feet 2½ inches apart, with their outer ends resting on the side walls of the station. The engineer was Mr. W. Paterson. The roofs over the east and west courts of the Alexandra Palace, Muswell Hill, are also of this type (Figure 6), with principals 53 feet 6 inches span placed 17 feet apart, it being found cheaper to truss the purlins than to place the principals nearer. The roof cost 10*l.* per square, including fixing and columns without covering (see Plate No. 51). See page 24.

The ornamental roof over the courtyard of Her Majesty's India Office is carried by a compound truss (see Figure 21). The length of the roof is 113 feet 6 inches, and the span is about 66 feet 3 inches, with a rise of the ridge above the springing 16 feet 4 inches, which depth is divided into two, the upper portion being composed of a truss 7 feet 6 inches deep, of the type shown at Figure 6, but strutted at the base, below which is connected a trapezoidal truss about 8 feet 10 inches deep, with ends inclined in continuation of the pitch of the upper truss, and braced in a similar way, while the central portion is in the shape of a rectangle divided into three bays, and braced with inclined struts, connected by tension bars.

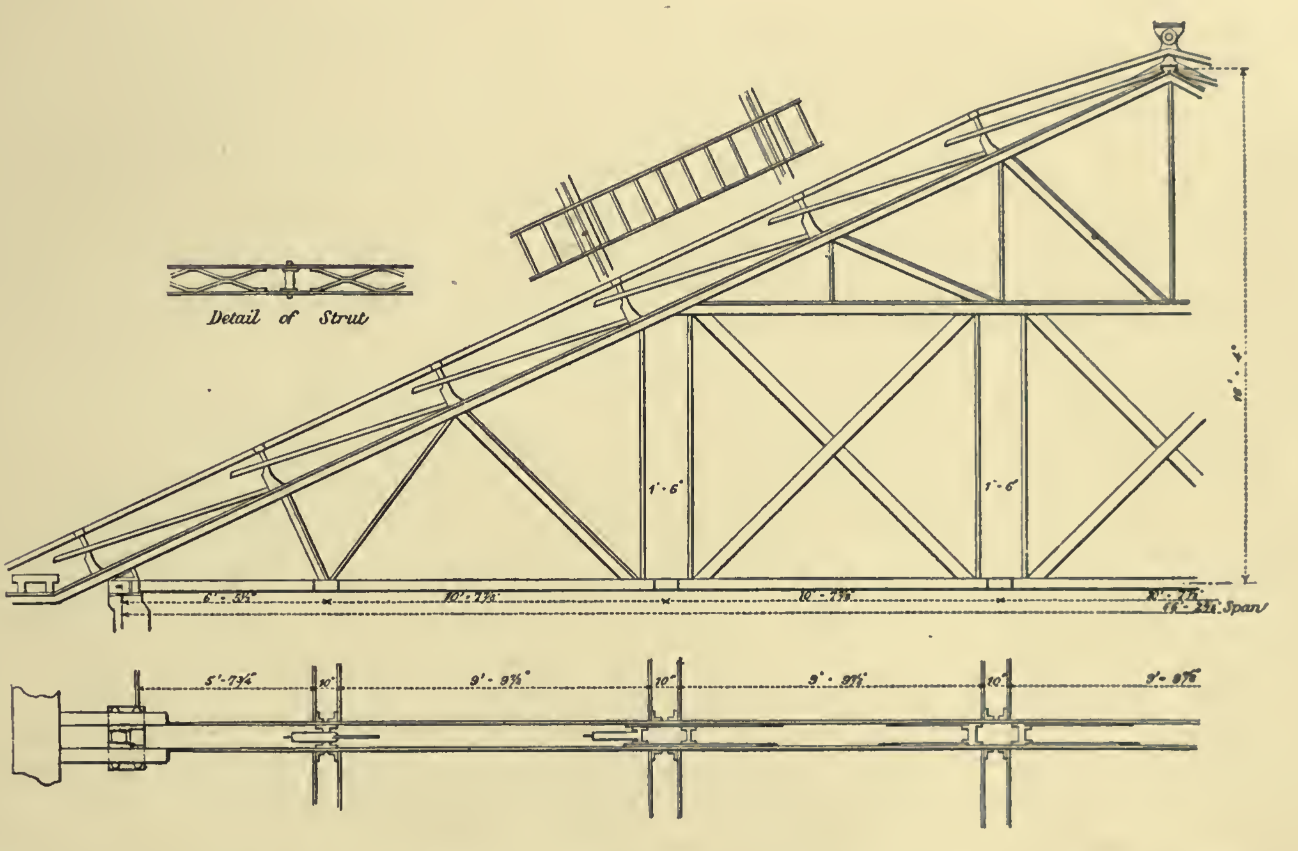
The roof over the Volunteer Drill Hall in Port Elizabeth is an example of Figure 7. The principals are 70 feet span, divided into eight bays, the angle irons and bars being connected by rivets at the attachments. The total rise of the top rib in the centre is 15 feet 1 inch, and that of the tie forming the bottom rib 5 feet 9 inches above the springing, giving a depth of truss of 9 feet 4 inches. The roof is covered with galvanised corrugated iron, No. 20 B.W.G., laid on felt over ¾-inch boarding fastened to the timber purlins, which are secured to the main ribs by angle-iron cleats. The ironwork cost 6*l.* 10*s.* per square (see Plate No. 24).

In designing a roof for a foreign country, where skilled labour is scarce and expensive, it is advisable to offer every facility for erecting the different parts and to make them as similar and interchangeable as possible. Connections formed by pins or bolts are more easily fitted than those

which require to be riveted together, and may be advantageously employed in a trussed roof, but riveted connections give greater rigidity.

Figure 9 is a modification of the queen-rod roof, and forms a very good type of truss. It has been adopted in the roof of the Victoria Station over the London Brighton and South Coast Railway, designed by Mr. Jacomb Hood. The trusses are of 50 feet span, supported on trussed girders 10 feet 9 inches deep, which run transversely and form two spans of 124 feet 7 inches and 117 feet 5 inches respectively, meeting over the centre of cast-iron columns 1 foot 6 inches in diameter. Cast-iron gutters are fixed on the top wrought-iron plate of the girders, and constructed to take a part of the strain in the top flange. The ironwork cost about 20*l.* per square (see Plates Nos. 25 and 26). The form of principal adopted in the Dover Harbour Station of the London Chatham

Fig. 21.



and Dover Railway, also resembles Figure 9. The span is about 44 feet, with principals placed 6 feet 6 inches apart and about 7 feet 6 inches deep, the rise of the top of the rafter being 9 feet, and the rise of the tie-rod 1 foot 6 inches above the springing. Figure 6 is to be preferred to Figure 9 for those roofs where it may be advisable to introduce longitudinal bracing between the principals in a vertical plane, and its vertical members are better adapted for roofs with hipped ends than Figure 9; but Figure 9 possesses the advantage of struts at right angles to the rafter, and, therefore, of minimum length; while in Figure 6 the inclination of the struts is generally different in each bay, and the last strut nearest the support is usually at a very unfavourable angle for resisting compression. At the same time it must be borne in mind that hipped rafters are a considerable support to a roof, and resist the wind pressure better than a gable. A combination of Figure 6 with Figure 9 is found in some constructions in which both the struts and ties are inclined, the struts being placed as nearly at right angles to the rafter as the design will permit, and thus their length is shortened, as compared with Figure 6, and the strain upon them reduced.

Figure 22 shows the first step taken in the direction of an arched form of construction. The roof over the Paris terminus of the Strasburg Railway is of this form in a span of 97 feet 6 inches. The arched rafter has a rise of 29 feet 6 inches, and the resistance to distortion under the influence of partial loading is provided for by light wrought-iron rods bracing the rafters together. This system illustrates what is known as a Mansard or curb roof, another good example of which may be seen in

the large span of the new North-Eastern Railway Station at Leeds, which may be described as consisting of two trusses of the type shown in Figure 1, meeting at a height of 28 feet 6 inches above the springing level, and tied together at the feet, forming a principal of about 89 feet span (see

Fig. 22.

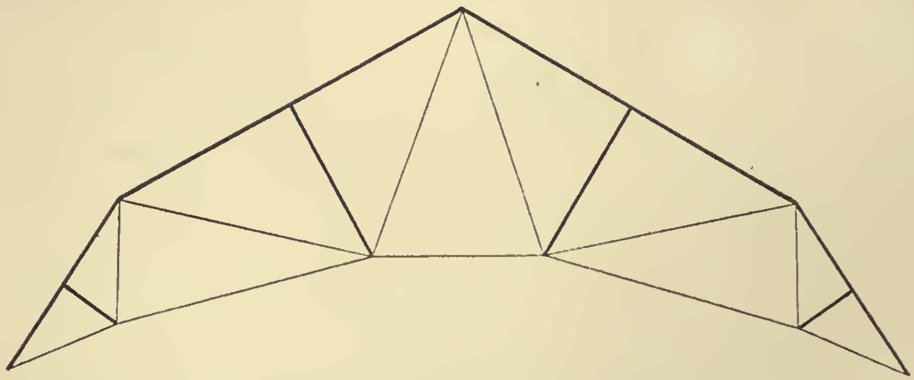
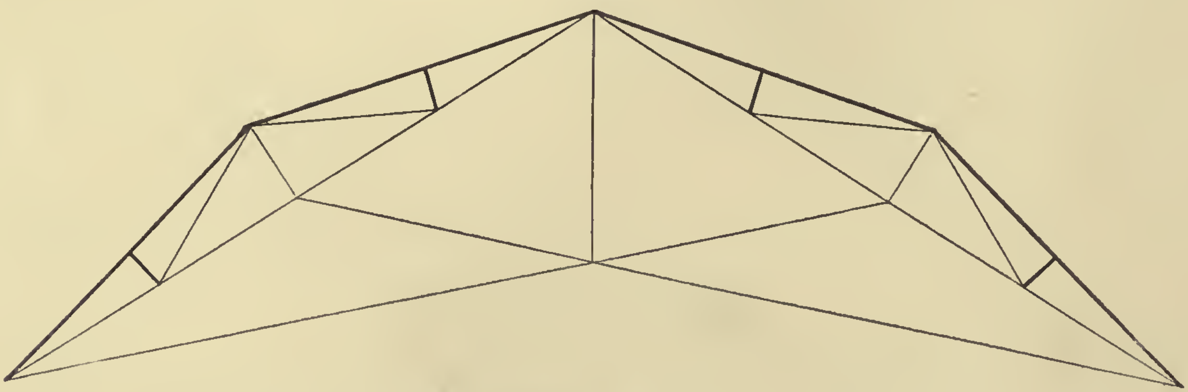


Figure 23). The centre span and that on the opposite side are of the same type of truss, averaging 69 feet and 86 feet respectively; but to suit the conditions of the ground, and the arrangement of platforms, the three spans each vary in width. The principals are placed 12 feet 8½ inches apart; and to resist the distortion due to a partial load, the centre of each side rafter is braced to the centre of the tie-rod, which is held up at the attachment by a king bolt. The merit of this form of truss is

Fig. 23.



that nearly all the bracing is in tension, but the repetition of the tie-rods does not present a good general appearance. The cost of the ironwork in this roof was about 22,000*l.* (see Plate No. 27).

In high roofs the action of the wind is one of the most considerable forces they have to sustain, and it is supposed to have been with the object of reducing their height that the Mansard or curb form of roof was suggested.

Figure 8 combines the advantage of a straight rafter roof with the pleasing effect of a graceful curve to the inner member of the rib, the necessity of tie-rods being done away with. A roof 162 feet 6 inches in length, and 50 feet wide, was constructed upon this type (Figure 8), for the Nitheroy Gasworks, Brazil, in 1868. The principals are 6 feet deep in the centre, and are supported on columns placed 12 feet 6 inches apart. The roof overhangs 5 feet on each side at the eaves, which are supported by cast-iron brackets. Great rigidity is given to the structure by the attachment of the brackets to the ends of the rafters and to the columns. In every roof where the trussed principals are likely at any time to be subjected to partial loading, they should be counter-braced by crossed diagonals between the verticals, and especially would this be necessary when erected with open sides in an exposed situation. The principals of the roof over the Wellington Pier, Bombay, were constructed similar to Figure 8, and counter-braced throughout.

Figure 3 exhibits a truss of segmental form, with radiating struts connected by diagonal braces and held in position by straining the tie-rods. This type of roof was adopted by the late Mr. R. Turner in the old Lime Street Station, Liverpool, with a span of 153 feet 6 inches, divided into seven bays. The distance between principals was 21 feet 6 inches, which space was trussed laterally

at each strut by purlins formed of three T irons, the centre T iron running direct from principal to principal, while those at the side branched off right and left at 5 feet from each other, so that they were attached to the girder in three points. Diagonal braces were fixed between two corresponding struts connected at the top with the purlins, and at the bottom in the adjoining principal with linking plates by bars of their own scantling. The ends of the principals were each fixed in a cast-iron chair resting on rollers over the supporting wall on one side, and fixed on the other side upon a cast-iron column. The cost was about 20*l.* per square (see also page 15). A similar form of truss has been adopted in the Snow Hill Station, Birmingham, designed by Mr. Thomas Vernon, of Cheltenham. This roof is divided into two spans, meeting over a central row of columns—one roof is 506 feet long, carried by twenty-four principals of 92 feet span, having a rise of 27 feet 6 inches, with a depth of truss equal to 9 feet, the rise of the tie-rod being 18 feet 6 inches above the springing. The other roof is 176 feet long, carried by nine principals of 58 feet 3 inches span, having a rise of 17 feet, with a depth of truss equal to 7 feet, the rise of the tie-rod being 10 feet above the springing level. The principals are placed 22 feet apart, connected by purlins of two kinds, viz. trussed T irons and lattice girders. The cost, including covering for the roof proper, was 13*l.* 4*s.* per square.

The circular or segmental form is the best adapted for wide spans, but in any very exposed situation both the last described roofs, as shown in Figure 3, would prove defective, as the counter-bracing applied to the centre bay is not extended to the side bays, so that when not uniformly loaded some of the ties are called upon to sustain compressive strain. In the Fenchurch Street Station roof, of 105 feet span, designed by Mr. G. Berkeley, in 1851, this contingency is provided for by counter-bracing every bay, as in Figure 5, where the struts are vertical. The roof over the new grain depôt at the Millwall Docks, designed and erected by Mr. Frederic E. Duckham, consists of twenty-one spans of 44 feet each by 211 feet, supported on columns 15 feet high, placed at distances apart of 15 feet, and connected by trussed angle-iron purlins. The main ribs are similar to Figure 3, with radial struts, but properly counter-braced, as in Figure 5. Each rib is divided into six bays, and is 8 feet 9 inches deep, the tie being nearly horizontal (see Figure 24). The cost, including corrugated iron and skylight, was only about 4*l.* per square.

Fig. 24.

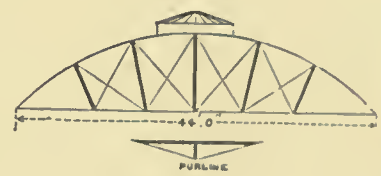


Figure 5 represents a truss on the bow-string principle, in which the verticals are constructed to act in compression while the inclined braces are considered to act in tension only. This form of roof was adopted in the Joint-line Station, at New Street, Birmingham, which comprises one of the largest areas in any single span. Its length is 840 feet, divided into thirty-five spaces by principals placed 24 feet apart, and varying in span from 212 feet to 190 feet 9 inches, with a rise about one-fifth of the span. Each truss is divided into thirteen bays, and the depth of the widest is about 23 feet, with the tie-rod raised about 17 feet 6 inches above the springing level. The main ribs are connected longitudinally by trussed timber purlins 8 feet apart, resting on the back of the principals and butting against one another, thus forming continuous lines from end to end of the roof, which are maintained by wind-ties springing from the foot of every alternate arch, and running diagonally across the roof to the foot of the fourteenth arch on the opposite side. The trusses are fixed on one side over brick pilasters, and on the other they rest on rollers placed over iron columns 2 feet in diameter, which act as pipes to convey away the water. The roof is terminated at each end with a gable screen, and ventilated at the top along the centre by an elevated ridge resting on louvre standards. It was completed in May 1854, and cost 17*l.* 15*s.* per square. The roof over the west-end terminus of the South-Eastern Railway, at Charing Cross, is divided into 14 spaces by 14 principals, in addition to the gable principal. The clear span is 166 feet (see Plate No. 29). The principals are trussed in a similar manner to Figure 5, and are placed 35 feet apart. Each truss is divided into nine bays. The rise of the tie-bar is 25 feet, and of the curved rib 45 feet above the springing level, giving a truss 20 feet deep at the centre. The trusses are fixed at one end and hinged to a saddle bearing at the other. There are no wind-ties, but two

intermediate trussed frames are introduced in each bay, with lattice-girder purlins resting on the lower flange of the rib of the principal, and attached securely to the principal at the top and bottom flanges with slotted holes, the purlins being all bound together by the intermediate framed ribs and the riveted sash bars. The roof cost 40*l.* per square. The roof over the City terminus of the South-Eastern Railway at Cannon Street, is trussed in the same way, and is divided into nineteen spaces by twenty principals, including gable. The principals have a clear span of 190 feet 4½ inches, with a rise of curved rib at the centre equal to 60 feet and rise of tie-bar 30 feet above the springing level, giving a truss 30 feet deep. The principals are placed 33 feet 6 inches apart, except where the station crosses Thames Street, at which point the distance between the principals is 35 feet 1½ inch, to suit the abutments of the bridge over that street. The height from the rails to the springing level is 46 feet. The main rib in each principal is 1 foot 9 inches deep and 1 foot 2 inches wide across the top and bottom flanges, with ⅜-inch web and connecting angle irons 3 inches by 3 inches by ½ inch. This section is the same throughout, and the rib is curved with a radius of 108 feet. The tie-rod is of uniform section throughout, $5\frac{5}{16}$ inches in diameter. The rib is trussed at eight points with vertical struts tied together at the bottom and braced diagonally as in Figure 5. These struts are made of two wrought-iron plates 10 inches by ½ inch, each stiffened on the outside with T irons 6 inches by 3 inches by ½ inch, and are kept apart by cast-iron distance pieces. The diagonal bracing consists of flat bars, varying in size from 6 inches by ⅝ inch in the centre to 6 inches by 1 inch at the springing. The main principals are connected by wrought-iron purlins 1 foot 8 inches deep, extending from rib to rib at intervals of 11 feet, and secured by bolts, with holes slotted to provide for expansion and contraction. The purlins are braced by one intermediate rib in each bay and by the sash bars and boarding (see Plate No. 28). The cost was 49*l.* 10*s.* per square. Both roofs are crowned with lanterns fitted with side louvres for ventilation. The main roof of the London Bridge terminus of the London Brighton and South Coast Railway is another example of this type of truss—see Figure 5. The span is 88 feet and the depth of truss 18 feet, the rise of the top rib being 27 feet and of the tie-rod 9 feet above the springing level. The principal trusses are placed 16 feet apart, with a light intermediate rib of trussed angle-irons resting on the wrought-iron purlins (see Plates Nos. 32 to 34).

In the recent competition for the new roof at the Exchange Station at Liverpool, the design which obtained the first prize consisted of three spans, each something over 100 feet, of the type shown in Figure 3, with vertical struts. If the diagonal members of the truss are constructed as struts as well as the vertical members, then cross diagonals would not be necessary; but in this case bracing as in Figure 5 should be preferred. A better arrangement where all the members are constructed as struts between the upper and lower connection is that shown in Figure 11, an example of which is found in the principal of the main roof over the Blackfriars passenger station of the London Chatham and Dover Railway. It is 87 feet 3 inches in span, and supported on columns 32 feet 3 inches apart. The total length is 401 feet 6 inches, and the whole roof is braced together by diagonal wind-ties. In the trussed principals which are of wrought iron, the top member is of angle iron, the tie-rods are flat bars with cast-iron distance pieces between them; the struts are flat bars filled in with angle iron and open plates; the wind-ties are ⅞-inch rods. The columns are held down with 1¼-inch bolts to stone bases carried on brick piers, and are connected longitudinally by a trussed girder which carries two intermediate ribs. The rise of the top curved rib is 22 feet and of the bottom rib forming the tie 13 feet above the springing, giving a depth of truss of 9 feet. Ventilation is effected through the purlins, which are of cast iron, having ornamental perforations for that purpose. The columns are hollow to carry off the rain-water. The roof was designed and erected under the direction of Mr. W. H. Thomas (see Plates Nos. 35 and 36). The roofs over the Woodside Station, at Birkenhead, are constructed in a similar manner. There are two spans of 97 feet 11 inches and 91 feet respectively, supported on the side walls of the station and meeting in the centre over a longitudinal row of columns placed 25 feet apart. The principals resemble Figure 11, and are 10 feet 4 inches deep (centres), with a rise of 25 feet from the springing level to the centre of the top rib. They are fixed in the centre to the columns and spandrels, but at the other end the shoes are provided with expansion rollers resting on the wall plates. The roof is

divided longitudinally in fifteen spaces by the main ribs, and surmounted by a longitudinal skylight 16 feet wide, with side louvre standards. The north-west corner is curved in plan, owing to the position of the site. The purlins consist of trussed T iron, and the whole is braced by diagonal wind-ties connecting three bays. The roof was built in 1877, and cost about 32*l.* per square.

The roof over the new Lime Street Station, Liverpool, is also composed of trusses framed as shown in Figure 11. The main portion, erected about ten years ago, consisted of principals of varying span, averaging 212 feet, with a depth of 22 feet 9 inches, measured from top of truss to arch of tie, which is raised 22 feet above the springing level. The station was enlarged in 1875. The span of the extension measures 191 feet, with a height in centre of 71 feet. The wrought-iron principals are similar in construction, and are placed 32 feet apart, connected by lattice purlins placed over the ribs, and provided with ventilators supporting the wood purlins upon which the sash bars rest. The principals are fixed over a double line of columns placed longitudinally at the junction of the spans. The curved rafter consists of a built-up girder section $14\frac{1}{2}$ inches deep with top and bottom flanges 12 inches wide by $\frac{1}{2}$ inch thick, the angle irons being $4\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{5}{8}$ inch, and the web plate $\frac{3}{4}$ inch thick. The main ties are formed entirely of a series of link bars $5\frac{1}{2}$ inches by $1\frac{5}{6}$ inch, four in number, connected at the junction of the struts by a turned steel bolt and nut $4\frac{5}{8}$ inches diameter. The struts are composed of four angle irons $2\frac{1}{4}$ inches by $2\frac{1}{4}$ inches by $\frac{3}{8}$ inch, with cast-iron distance pieces secured with hoops of half round iron 1 inch by $\frac{1}{2}$ inch. The glazed portion consists of rough plate glass of $\frac{3}{8}$ inch thickness, in panes measuring 10 feet in length; such portions as are not covered with glass are boarded and covered with Messrs. Braby and Co's. Vielle Montagne zinc sheeting of Italian pattern. The columns are 20 feet high, with a mean diameter of 3 feet. The length of the roof is 645 feet, and cost 30*l.* per square, exclusive of gables (see Plates Nos. 37 and 38).

The Amsterdam Station of the Dutch Rhenish Railway, designed by Mr. R. M. Ordish, is covered by a roof as shown in Figure 11, but with straight instead of curved members between the points of connection. The main principals are each 120 feet span placed 25 feet apart, and are connected to cast-iron shoes fixed over the top of hollow cast-iron columns which carry off the rain-water and are joined on the top by a gutter which acts as a girder for supporting the lower end of the roof covering in each bay. The compression members of the principals consist of straight lengths of cast-iron tubes 8 inches diameter, turned accurately at their abutting ends, and the tie-bars of two flat bar links 4 inches by $\frac{7}{8}$ inch, the diagonals being formed of double flat bars 6 inches by $\frac{5}{16}$ inch. The arch thus formed has a total rise of 30 feet, with a rise of tie-bar 17 feet, giving a depth of truss 13 feet in the centre. The purlins are also cast iron. The wind-ties are bars 4 inches by $\frac{3}{8}$ inch. The station is 300 feet long, and presents a cheap and very strong form of roof.

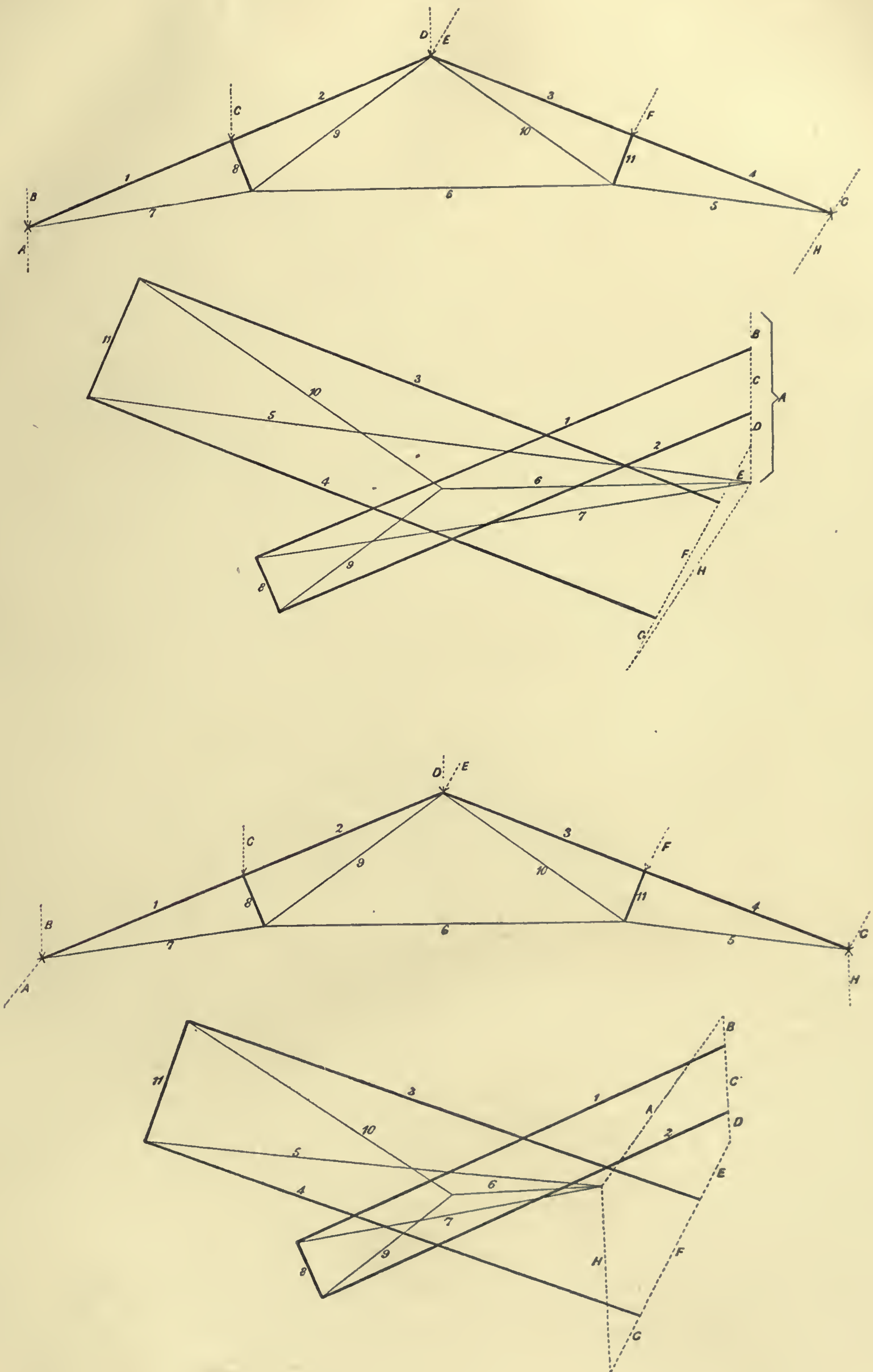
The loads on a roof are partly permanent and partly occasional. The greatest accidental load of a statical nature which can come upon a roof is when it is covered with snow, and the greatest dynamical, when one half of it is exposed to the action of a violent storm or wind pressure. The former is provided for by making the roof strong enough in every part to bear this maximum load, in addition to the permanent load of its own weight, and the latter by a proper arrangement of bracing and wind-ties to resist distortion. The weight of snow varies in amount in different countries and in different positions. As in this country snow is not likely, in the presence of a strong wind, to accumulate on a roof more than about 9 inches in depth, it is unnecessary to allow for a greater distributed load than 8 lb. per square foot of horizontal surface covered. The pressure of wind is more variable, as it does not always blow in the same direction. In finding the strains on a roof, it is incorrect to assume that the wind force acting vertically is the worst case that could happen. Its pressure depends not only upon its velocity, but also upon the angle of incidence at which it strikes the roof. It is difficult to determine the limits of this deviation from the normal, but it may be estimated approximately, and the effective normal pressure of the wind acting at any point on the space between the main ribs calculated, while the non-effective tangential pressure may be practically disregarded. In this country it is sufficient to allow for a horizontal pressure of 40 lb. or 45 lb. per square foot of surface directly opposed to it, acting broadway on either side of the roof, as representing the equivalent of wind and snow pressure. The ordinary force of gales amounts to from 20 to 30 lb. a square foot on a surface perpendicular to their

direction. All roofs settle a little, so that it is advisable with large spans to fix the trusses at one end only, and it is found the most economical plan to fix the side opposite to that on which the heaviest gales are likely to blow. In the annexed diagram (see Figure 25) the inclined dotted lines attached to the trusses represent the direction of the resultant pressure produced by the wind force and dead load, and the length of the lines in the diagram of strains show the respective amount of strain in the different members of each truss. Thus it will be seen that the truss fixed on the leeward side, and left free to expand or contract on the windward side, has the amount of strain in its component parts greatly diminished when compared with the same truss fixed on the windward side, the data in each calculation being alike. The thick lines show the members in compression, and the thin lines those in tension, while the black dotted lines show the external forces, the greatest stresses being when the leeward foot is free. A simple form of truss has been assumed to illustrate the principle, but the result would be similar in any case, and shows the economy to be effected by observing the direction of the prevailing wind in any situation, and fixing the roof principals as near as possible on the leeward side.

For moderate spans, bearing surfaces accurately planed are better than small rollers. Roller frames may tend to lessen the racking motion produced by expansion and contraction of an ordinary roof, but do not prevent it. An examination of the Exeter Station roof of 132 feet span, some time after its erection, proved that the rollers which had been provided at the shoes to the principals in the outer wall had not moved, so that they might have been dispensed with. During the Hammersmith Bridge inquiry in 1869, it was noticed that the rollers under the chain connections in the towers had rusted into their saddles or bearings, there being evidence of the chains having rubbed their under surface upon the rollers, rendering the friction of the rollers so great as to require the tower itself to ease before the rusty rollers would rotate. Mr. Brunel nearly always provided for variations of temperature in his structures; but time and practice have since proved the effect to be much less than was at first supposed. Care should, however, be taken that the wall or other support at the fixed end of a roof of a large span is capable of resisting the thrust produced when the wind is blowing on either side of the roof with its full force, and the rollers at the other end are on the point of motion; also that the support at the roller end is capable of sustaining the pressure under every variety of loading. The wind pressure may at any moment act in a vertical direction, depressing the main rafters and producing an uneven stress upon the connection at the ends, which causes the roller on the inner side to be more compressed than the others, and tends to crush it. In the Cannon Street roof, provision is made to prevent this by attaching the end of the principal to a special casting, which is connected to another casting resting on the rollers by a circular joint secured with a pin; so that, whatever the inclination of the main rib may become, the hinging of the joint causes the stress to pass through the centre of the group of rollers, and thus to be evenly distributed over them. It is usual to brace a roof diagonally, to enable it to resist the effects of wind blowing at an angle with the axis of the roof, by iron ties passing up from the springing to the ridge in an oblique direction and attached to the under side of the purlins. In some part of the length of these ties a coupling screw is inserted to admit of proper adjustment. In many roofs these wind-ties are spread all over the structure. In the roof over the Drill Hall, Forrest Road, Edinburgh, designed by Mr. R. H. Bow, the wind bracing is confined to two bays. The roof consists of principals similar to Figure 12, with a span of 97 feet 6 inches, fixed at one end and resting on rollers at the other. There are nine of these trusses 13 feet 6 inches deep, which with two stone gables give ten equal bays in a total length of 135 feet. The bays next the end bays are braced with diagonal ties fixed throughout at a favourable angle, the lateral stiffness of the six intermediate and of the two end bays being secured by their purlin connections. The radius of the curve of the top flange of the principals is 57 feet 6 inches, and the rise of the tie-bar in the centre is 13 feet 6 inches. The wind-ties are connected to the lower face of the upper angle irons of the arch, underneath the purlins which are attached to the upper face. Besides looking well, this disposition offers facilities in the erection.

Figure 4 illustrates a queen-post truss derived from the old timber system, but generally modified in its recent application to iron structures. The roof over the Earl's Court Station of the

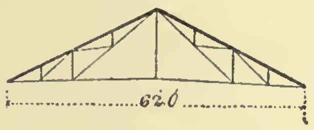
Fig. 25.



Metropolitan District Railway, designed by Mr. John Wolfe Barry (see Figure 26), consists of principals formed of two inverted queen-post trusses, with vertical members braced together and connected by purlins, which are made deeper at their junction with the principals than in the centre, so as to stiffen the ribs longitudinally. The principals are about 96 feet span, and are placed 20 feet apart. One end of each principal rests on a single steel roller. The purlins are not at right angles to the rafter, but vertical, as in the roof over the Ealing Station (see Figure 27). There is no wind bracing throughout the roof, but diagonal bracing in the two end bays, which counteracts the pressure of the wind endways. The roof is closed at one end by the booking-offices, and at the other end with a gable screen formed by trussing a main rib longitudinally as well as bracing it transversely. In the construction of this roof, the short-link connection usually adopted in the main truss had been done away with. Instead of terminating one rod and uniting it by a short link to the next connection, it was here made all in one, so that the bar had two heads forged on to it at the end in which the bolt holes were drilled (see Plate No. 39). Provision is made for ventilation in standards fixed over the purlins.

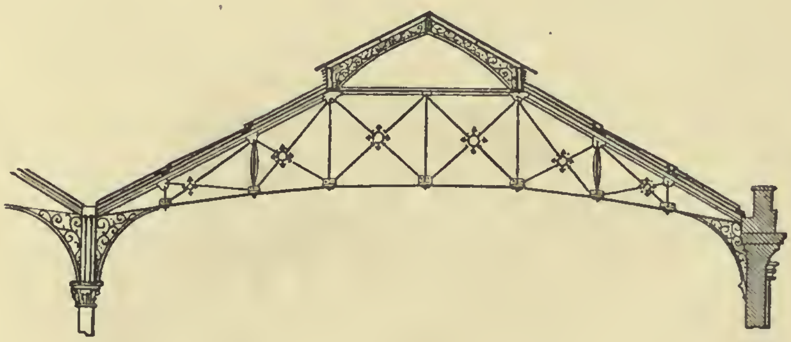
Fig. 26.

Fig. 27.



The roof over the Broad Street Station belonging to the London and North-Western Railway is in two spans, of 95 feet each. The principal resembles a queen-post truss shown in Figure 4, but was originally designed to act as a tied arch braced with tension rods. In each side-inclined rafter one vertical strut is inserted, to obviate the effects of unequal loading. The principals are placed 36 feet 10 inches apart, resting on the outer walls, and meeting over a central line of columns which are connected with wrought-iron lattice spandrel girders. The principals are about 12 feet 6 inches deep in the centre, and the rise of the transverse tie-rod is about 4 feet 6 inches above the springing level (see Figure 28). Each span is surmounted in the centre with a cast-iron arched

Fig. 28.

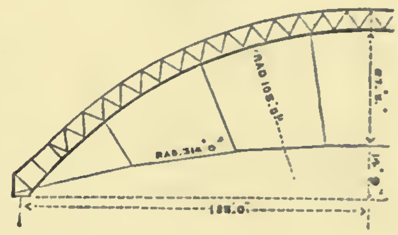


spandrel ridge, to which are attached side louvres for ventilation. The whole roof is well secured by wind-ties, which the construction here adopted renders especially necessary to maintain the structure in position. The roof was erected in 1865 (see Plate No. 40). A similar form has been adopted in the roof over the Preston Station, consisting of principals placed 32 feet apart, the spans in one length varying from 77 feet to 47 feet connected on one side to spans of 51 feet, and on the other side to spans of 33 feet over the platform buildings, there being an additional outside length of spans varying from 66 feet to 50 feet, forming a covering about 992 feet long by a varying width in four spans.

The type of roof adopted in the west-end terminus of the London Chatham and Dover Railway at Victoria Station—also at the Central Station, Liverpool, and Queen Street Station, Glasgow, may be described as a tied arch with the tie-bar looped up, the tie taking the place of abutments to resist the thrust of the upper part of the arch. The roof at the Victoria Station consists of two crescent arches of unequal length and unequal span, as it was found necessary in order to meet the then existing arrangements of the station to make one span 127 feet 4 inches wide, and the other 129 feet wide, the length of the former being 455 feet, and of the latter 385 feet. The principals are 21 feet deep from the centre of the top rib to the centre of transverse tie, which is raised 8 feet

6 inches above the springing line. They are placed 35 feet apart, with two intermediate ribs springing from the gutters resting on cast-iron spandrel girders, which connect the top of the columns under the feet of the principals together. The covering is supported by eight trussed and six trellised purlins, which are bolted to the main ribs, and every two bays are braced with diagonal wind-ties. The outer gutters rest on the side walls of the station, and the middle columns serve as pipes to drain the central gutter. Expansion rollers are provided under the foot of each principal over each side wall. Ventilation is obtained by a raised covering, trussed as in Figure 1, over the centre of each roof. The work was designed by Mr. John Fowler, and the cost altogether was 27*l.* 13*s.* 4*d.* per square (see Plates Nos. 41 to 44). The roof over the Central Station, Liverpool, is similarly constructed. The main ribs are 160 feet span, with a rise of 40 feet in the centre, the tie also having a rise of 14 feet. This roof is one of the boldest designs of its kind, the principals being placed at the unusually great interval apart of 55 feet to meet the requirements of the adjoining buildings. There are nine principals, one of which supports a gable screen, which is trussed against the action of the wind, while the other end of the roof is closed by the station buildings. The main ribs are connected by lattice purlins, which support five intermediate ribs. The tie-rods are of steel. The roof is 495 feet in length and is ventilated by open spandrels carrying a raised skylight along the ridge. The roof was designed by Mr. John Fowler, and the cost of the iron and steel was 14*l.* 1*s.* per square. The roof over the Queen Street Station, Glasgow, belonging to the North British Railway Company (see Figure 29) is about 415 feet long, and 170 feet span from centre to centre of supporting columns, which are placed at a distance of 41 feet 6 inches longitudinally. This roof is the largest span of its kind, and is carried by nine principals in addition to two end gables. The rise of the centre of the top rib of the principal is 44 feet, and the rise of the tie-rods 14 feet 9 inches above the springing level. The side columns are connected by lattice girders carrying the gutter, and each bay between the main ribs is divided into five spaces by four intermediate ribs supported by lattice purlins placed 27 feet 9½ inches apart, with secondary purlins carrying the glass. The tie-rods are of steel. The ironwork cost 15*l.* per square, exclusive of foundations (see Plate No. 45). The roof is covered with glass to a large extent, but not on any patent system, and cost 21*l.* per square with covering complete. The proportion of area covered was about one-half glass, one-fourth of sheet lead on sarking, and one-fourth of slates on sarking.

Fig. 29.

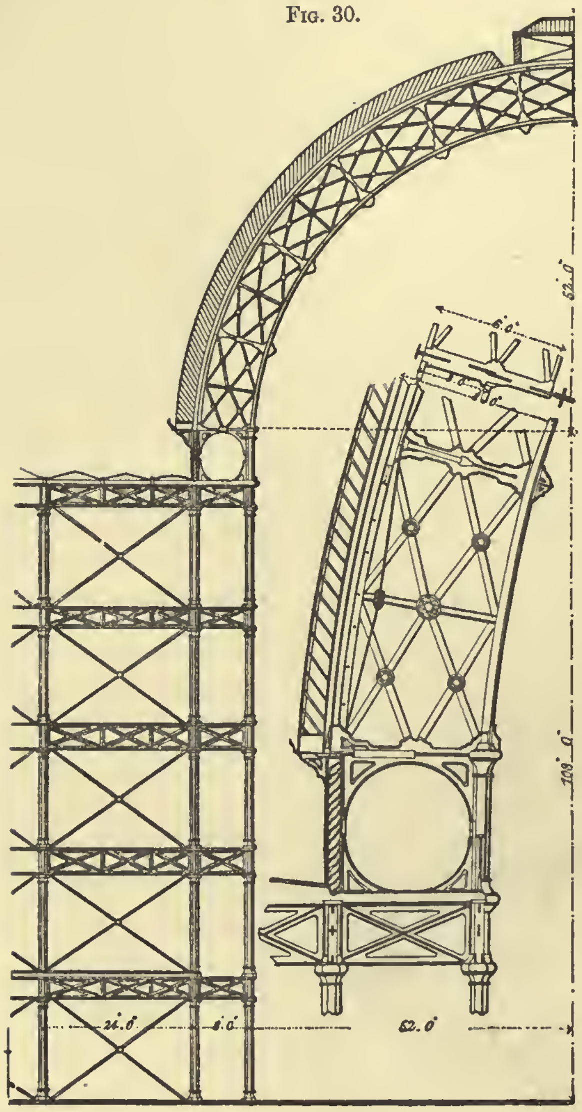


The general adoption of iron roofs of large span is comparatively of recent date. Beyond a span of 50 feet, the question arises whether the roof shall be made in one or more spans. The late Professor Rankine held the opinion that the roof should, where possible, be in a single span over the whole station, but the late Sir Charles Fox preferred roofs of 50 feet or 60 feet spans as being the cheapest. If intermediate pillars are used, they should be placed in the middle of broad platforms. A comparison of the two stations at Victoria, London, shows this. In the case of the London Chatham and Dover Railway Station, they are now in the centre of the narrowest platform, whereas, in the London Brighton and South Coast Railway Station, they are in the centre of a broad carriage road. Of course, the adoption of very large spans is more expensive than dividing the space into two or three moderate spans, but there are the advantages of (1) freedom from all intermediate supports, giving facilities in laying out the space to the greatest advantage, or in subsequently altering the arrangements, and this freedom is especially valuable, when it is required to transfer the traffic of the station, from one line to another diagonally, at the shortest possible intervals; (2) getting rid of annoyance of snow lodging in the valleys; and (3) the grander architectural effect of the structure, whether trussed or arched. The stability of an arched roof increases with its weight and size. It may, however, be generally accepted, as stated by Mr. Matheson in his useful and practical book entitled 'Works in Iron,' that an arched roof usually costs more than a trussed roof if the expense of the abutments be included. But if, by the position or arrangement of the building, abutments already exist, or if for other reasons they have to be provided, then an arched roof may be better and cheaper than a trussed roof.

The plate or solid type of arch has been largely used for roofs of comparatively small span. Examples of this form can be seen at the stations of the Metropolitan Railway, the largest span of which is 90 feet, at High Street, Kensington. The underground stations being in a cutting, a ready-made abutment exists to take the thrust of the arch, and little or no transverse bracing is needed.

It is evident that, if strength alone be considered, the proper form of a roof is that which puts the whole in equilibrium, so that it would stand in that shape, supposing all the joints to be flexible. Any departure from this form renders the component parts subject to strain, and bracing is necessary to be introduced to maintain the form adopted. The circle is the curve of equilibrium for a uniform normal pressure, but the parabola is the curve of equilibrium for a uniformly distributed vertical load all over the span. The parabola has also a slight advantage over the circular rib in the event of unequal loading; but, as the rise of the arch is diminished, the circular and parabolic curves come so close together as practically to coincide.

Fig. 30.



It is often necessary to provide for the feet of true arched ribs to spring out a little during erection, in order to fit the supporting structure. This was the case in the Amsterdam Crystal Palace, the ribs of which were made to spring out in erection $2\frac{5}{8}$ inches. This roof covered an area of 130 feet $8\frac{5}{8}$ inches by 64 feet $1\frac{1}{4}$ inch on each side of an oval dome, with an entire length of nave of 329 feet 1 inch.

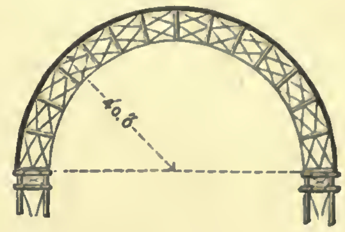
The arched ribs of the Crystal Palace roof, Sydenham, throw a very small horizontal thrust upon their supporting structure, being constructed of sufficient depth to act as a girder (see Figure 30). The large roof has a span of 104 feet, and the smaller span 56 feet. The details are similar. The horizontal thrust of the main rib is transmitted by a cast-iron framework to a system of columns connected by cast-iron girders and diagonal bracing fixed to the ends of girders by keys. The whole of the supporting structure up to this frame is very rigid, for on one side below floor level there are cast-iron girders fastened to brick foundations, and on the other side a fire-proof flooring of brick arches. Thus the portion of the thrust arising from pressure of wind, snow, &c., which the rib does not sustain is easily overcome. There are two kinds of purlins employed, one 72 feet long and 3 feet deep, and the other 24 feet long and 6 feet deep, the latter serving to brace each two ribs of one pair together, while the former act as pure purlins, supporting the intermediate rafters. A special arrangement was made for bracing the purlins sideways to these intermediate ribs. The covering of the roof is on the ridge-and-furrow principle, and the rain-water is conveyed to the drain-pipes by hollow columns. Most of the girders and columns employed at the Crystal Palace are the same as those used in the Great Exhibition building of 1851.

The Manchester Art Treasures Exhibition building of 1857 was covered with three longitudinal semicircular roofs. The central hall or nave, which formed the main feature of the building, was 56 feet wide, and each aisle 24 feet wide, making a total breadth of 104 feet by a length of 700 feet. The hall was crossed at the western end by a transept of the same height and breadth as the central portion, and at a distance of 500 feet from the entrance. On each side of the aisles the building was extended in wings for a distance of 450 feet. The semicircular roofs were supported upon rows of

columns standing in pairs athwart the building, and the principals rested alternately upon the columns and connecting girders. The crown of the centre arch was glazed for a breadth of 30 feet at the top, which stood at an altitude of 65 feet above the floor.

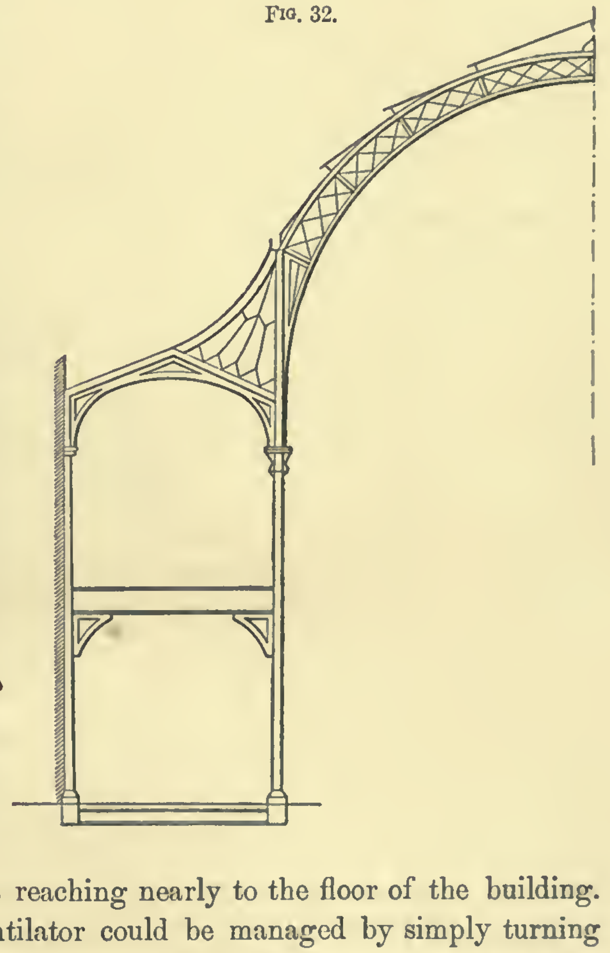
The principals of the roof over the Aquarium, Westminster, resemble those at the Crystal Palace, Sydenham. The ribs are semicircular in form (see Figure 31), having a radius of outer side or back of rib, equal to 40 feet 4 inches, and are placed 20 feet apart, with two intermediate ribs in each bay, supported by six lattice purlins. The main ribs are braced together in pairs, these pairs occurring at intervals of 60 feet and 40 feet. The building was designed by Mr. A. Bedborough (see Plate No. 46).

Fig. 31.



The roof of the Winter Garden of the Dublin Exhibition of 1865 covered a space 353 feet 6 inches by 50 feet 6 inches, having a transept 33 feet 8 inches wide by 50 feet 6 inches (see Figure 32). The thrust of the arched rib, the outline of which was semicircular, was resisted without the assistance of diagonal bracing, which although forming so great an obstruction, as every one who has been to the Crystal Palace, Sydenham, must have noticed, had hitherto been generally adopted. A flying buttress fixed to the column was here substituted for diagonal bracing, and the thrust of the main rib was conveyed to the second tier columns, which were firmly secured to small arched roofed girders, and connected to the first tier columns. The effect of this was to produce a transverse strain upon the columns, which had therefore to be increased in thickness at the sides, where they were exposed to the strain. As soon as the first tier columns were firmly fastened to the transverse bracket girders at the top, and to girders 1 foot 6 inches deep under floor level, a complete rigid framework was produced, capable of taking the thrust of the arched rib without the assistance of diagonal bracing. The gallery floor was trussed by rods of wrought iron arranged diagonally in plan, thus causing the principal portion of the permanent and moving load of the gallery to be immediately conveyed to the columns, instead of being transmitted by the girders. The truss being thus arranged formed also a horizontal bracing to the galleries, and the girders were left to take up the thrust of the ribs. A rather original mode of ventilation was adopted in this roof. The main ribs carried in the centre cast-iron standards connected at the top on both sides by an angle iron which supported the covering. The space between these two angle irons was used for ventilation, and could be opened or shut by means of a valve, consisting of a piece of convex sheet iron fixed to a rod running along the roof, and having a bearing in each of the cast-iron standards. Pulleys and balance-weights were connected to this rod at various points, by means of cords reaching nearly to the floor of the building. By this contrivance the opening or closing of the ventilator could be managed by simply turning the valve. The ridge consisted of a piece of corrugated zinc fixed on cast-iron supports covering the whole apparatus. The buttresses, columns, gutters, and girders throughout the building were entirely of cast iron, but the arched ribs of the main roof were of wrought iron. The purlins were also of cast iron, the webs of which were ornamentally perforated, the perforations being glazed, and the joints of the purlins chipped. The main ribs are 1 foot 6 inches deep at the crown, and 2 feet 8 inches deep at the springing. The radius of the intrados of the arched principal is 20 feet 6½ inches, and of the extrados 28 feet 1½ inch. The purlins are 16 feet

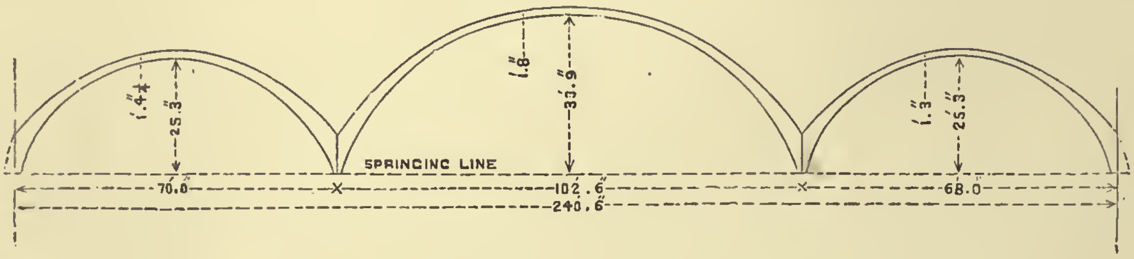
Fig. 32.



10 inches in length, $9\frac{3}{4}$ inches in height, and $\frac{3}{8}$ inch thick, the bottom flange being $\frac{1}{2}$ inch thick, and are connected firmly to the rib by two ornamental brackets, fixed by four bolts 1 inch diameter, which serve to increase the amount of lateral stiffness in the structure. The building was designed by Mr. Alfred G. Jones, architect. The ironwork is now being re-erected under the superintendence of Messrs. Bell, Miller, and Bell, at Battersea Park, Surrey, for the Albert Exhibition Palace.

The main roof over the Paddington Station of the Great Western Railway is divided into three spans (see Figure 33). The centre span is 102 feet 6 inches in width measuring from centre to centre of supporting columns, and forms an arch having a clear headway of 33 feet 9 inches above the springing level. The side spans are similar in construction, and are 68 feet and 70 feet wide from centre to centre of supports, with a rise of 25 feet 3 inches above the springing level to the intrados of the arch. The columns are placed 30 feet apart, and are connected by trussed girders, which

Fig. 33.



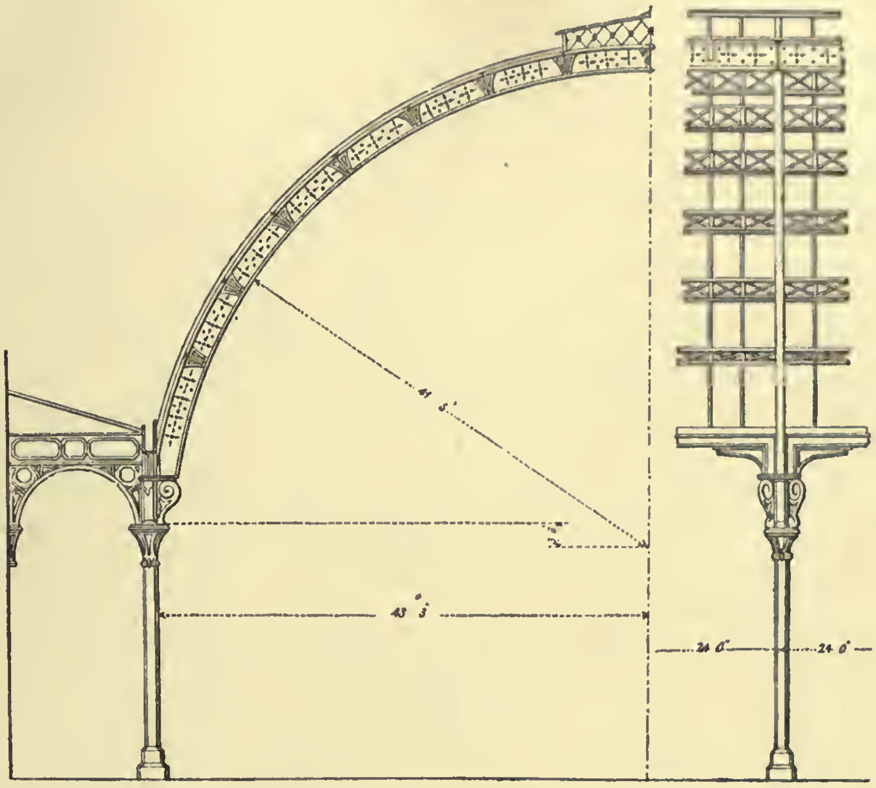
carry two arched ribs in each bay. The roof is about 700 feet long and is divided into seven spaces between columns at each end of the station, with six spaces in the centre and two intermediate transepts about 50 feet wide. The transepts are formed by arched ribs crossing each other diagonally and give great lateral stiffness to the roof. The girders connecting the heads of columns were also omitted at the transept, with the original intention of constructing a traversing arrangement to convey railway carriages across the station from one line to another, without the use of a turntable. The roof is glazed on the ridge-and-furrow system, following the curve of the roof, and carried on the transverse ribs, which are braced together by nine pairs of straps in each division crossing each other diagonally, and connected with the top flange of one principal and the bottom flange of the next. The roof is closed by an ornamental screen at each end. The roof cost 19*l.* per square, exclusive of columns and girders. The web of the principals has a neat design of holes punched out of the solid plates. The larger holes were made with a simple screw press, having long levers and heavy weights attached to them. This method seems to be the right way of treating wrought-iron plates, the web only remaining where it acts in a similar manner to diagonals, and in the author's opinion produces a much better effect than when raised ornaments are used.

The roof over the Market Hall, at Derby (see Figure 34), covers a rectangle 192 feet long and 86 feet 6 inches wide, and is supported on columns 22 feet high. The roof is divided into eight bays of 24 feet each. The principals consist of wrought-iron arched ribs, the inner and outer curves being true circles struck from the same centre, with radii of 43 feet 9 inches and 41 feet 5 inches respectively, the springing of the rib being 7 feet 6 inches above the centre. The rib is of the same depth throughout, and consists of $\frac{5}{16}$ inch thickness of web, with holes punched for sake of ornament, as in the Paddington Station roof, and connected with top and bottom flanges formed of two angle irons $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{7}{16}$ inch. The rib carries wrought-iron lattice purlins at intervals of 6 feet 9 inches. At every alternate supporting place of the purlins the web of the main rib is joined by a plate 1 foot 9 inches by $10\frac{1}{2}$ inches by $\frac{1}{2}$ inch thick, which plate is also riveted on to the web at the other purlins as a strengthening plate. The roof is hipped at both ends, and therefore there are only five ordinary principals of 81 feet 5 inches clear span. No provision is made for any additional horizontal thrust such as would arise from pressure of wind or snow, the roof offering a very great resistance in its longitudinal direction.

The Agricultural Hall, Islington, was designed by the late Mr. Frederick Peck, and built in 1862. The span of the central roof is 125 feet (see Figure 35), with a rise of 51 feet above the springing level. The principals are 24 feet apart, and are connected by longitudinal trussed purlins and wind-ties; the main principals rest upon a double row of braced columns, forming a base of sufficient

width to resist the thrust which is conveyed through the gallery girders to the outer walls. The roof cost 12*l.* 15*s.* per square, exclusive of erection and covering. The roof over the Coventry

Fig. 34.



Market Hall, designed by Messrs. Coe and Robinson (see Figure 36), is in a single span of 90 feet springing from the ground, and constructed somewhat similarly to the main roof of the Agricultural Hall. The centre of the top of the arch is 45 feet above the ground, and the thrust of

Fig. 35.

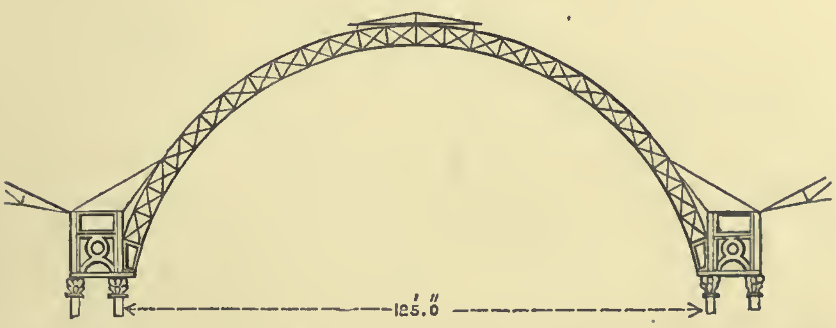
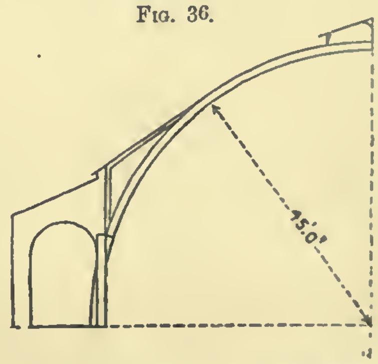


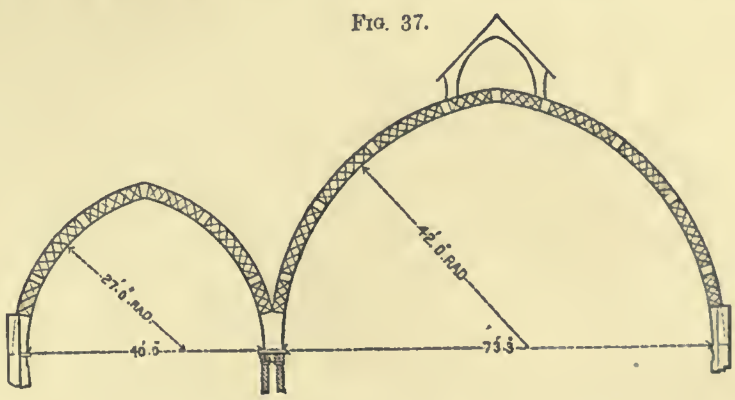
Fig. 36.



the arch is conveyed through a side arch to the main wall of the building. The principals are placed about 8 feet apart, and connected by trussed iron purlins.

The roof over the Middlesborough Station of the North-Eastern Railway is divided into two

Fig. 37.



spans of unequal length (see Figure 37). The main roof is 309 feet long, and is composed of principals of 76 feet 6 inches (centres) in width, formed in a pointed arch shape, having a radius to

each side of 42 feet, and meeting at the top, over which is fixed an ornamental ridge, fitted with side louvres for ventilation; and at each end of the station two main ribs are placed close together to carry the screen. The main ribs of the side roof are similar in construction, with a radius of rib equal to 27 feet struck from two centres, forming a roof of 42 feet 9 inches (centres) wide; the length is 183 feet, and each span is divided longitudinally between the end walls into nine spaces by eight double columns, over which the principals of the two roofs meet. The columns are connected by spandrel girders carrying two intermediate ribs in each bay; the feet of the other end of the principals rest on side walls, which also carry the remaining ribs of the single roof, and are constructed to take the thrust of the outside ribs. The roof was designed in 1876 by Mr. W. Peachey (see Plates Nos. 47 and 48).

The main ribs in the roof over the Great Hall in the Alexandra Palace are 1 foot 10 inches deep, with a radius of 39 feet 7 inches (see Figure 38). They are placed 25 feet apart, and are surmounted with a braced rib giving a straight incline of rafter for the covering; the springing line being 50 feet 6 inches from the floor. The late Mr. J. Johnson was the architect (see Plates Nos. 49 to 51).

The roof over the goods station of the Great Northern Railway at Bradford consists of arched principals of 103 feet 10 inches span placed 20 feet apart. The main rib is 2 feet deep all round

Fig. 38.

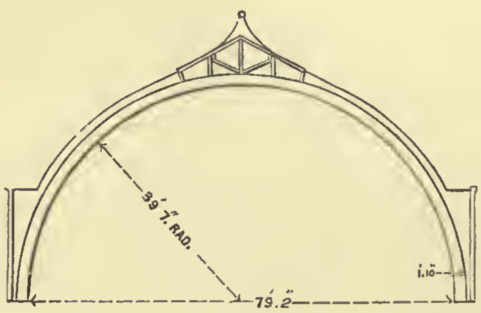
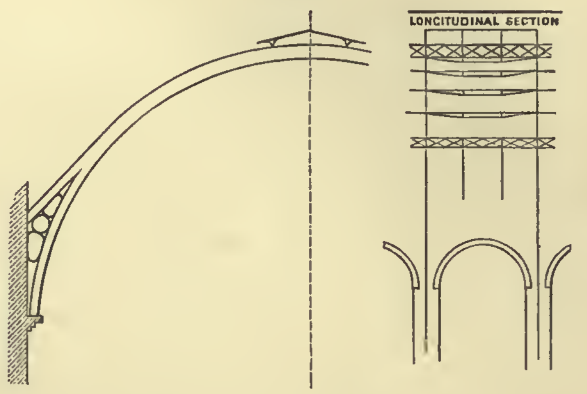


Fig. 39.



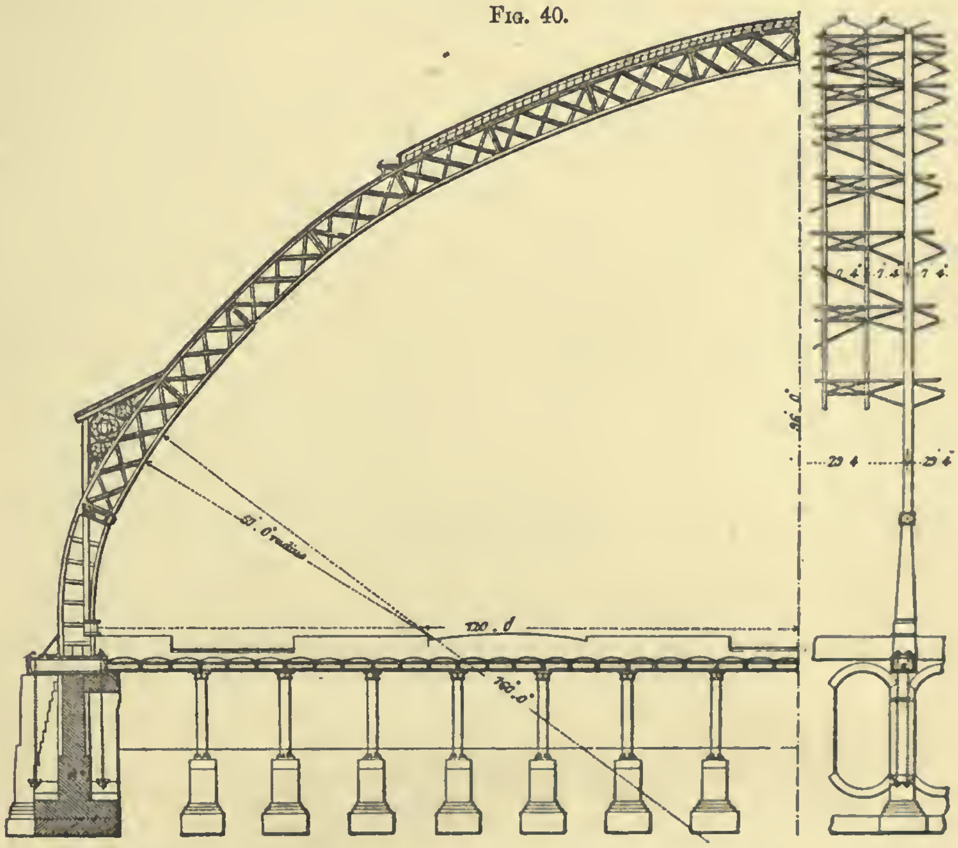
the arch, and is formed of angle iron, with flange and ornamental quatrefoil web plates; the intrados of the arch has a radius of 52 feet. This roof was designed by the late Mr. John Fraser, and its principal dimensions have been adopted by Mr. R. Johnson (see Figure 39) in the span over the arrival platform of the terminus station roof of the Great Northern Railway at King's Cross (see Plate No. 52). The main ribs are connected by trussed T-iron purlins, carrying two intermediate ribs. The roof consists of two spans of 105 feet 3 inches each, and the thrust on the outer side is taken by a heavy wood-trussed roof over the cab-rank. The web plates of the main ribs are plain. There is no diagonal wind bracing. In the last bay at the north end the purlins are made of a stronger section than the others, and T-iron bracing is introduced to sustain the lateral thrust of the roof. The cost of the roof, including a contract for the travelling scaffold used in the erection, was about 20,000*l.* The roof over the departure platform is formed of timber principals 106 feet span, with cast-iron spandrels similar to those in the new iron roof over the arrival platform. There are 39 bays of 20 feet each, which, together with one bay of 11 feet at the gable end, gives a total length of 791 feet.

The largest timber roof ever designed was made for the Imperial Riding House at Moscow, and consisted of an arched beam 235 feet span, the arch being formed of three thicknesses of timber, notched out to prevent their sliding on one another, and braced by suspension pieces and diagonal bracing, which were connected with a horizontal tie-rod jointing the feet at the springing.

The St. Pancras Station roof of the Midland Railway (Figure 40) is the largest single span that exists in any continuous length, and is 240 feet clear at the springing line. The form differs from both the circle and the parabola, the curve of equilibrium varying but slightly from the neutral line of the arch rib adopted, so that the transverse stresses arising from the weight of the roof itself are small. The arch was made slightly pointed at the top, because it was considered that this form possessed

advantages in resisting the lateral pressure of the wind. Each half of the main ribs consists of two segments of circles, with radii of 57 feet and 160 feet respectively, meeting in the centre, at a height of 96 feet above the level of the platform. The principals are placed 29 feet 4 inches apart, and the roof is 690 feet long. The section of the rib varies to some extent near the springing, the lower end of the rafter in a roof having to resist the maximum strain. There are twenty-five of these main ribs in the roof, between which trussed purlins at every 18 feet 6 inches, carry the intermediate ribs. The purlins help to stiffen the lower flanges of the main ribs longitudinally, and the whole is braced diagonally. The horizontal thrust of this roof is chiefly taken by the heavy brick piers acting as abutments, the feet of the ribs being each secured to an anchor plate built into the wall, and strongly fastened down by four bolts each 3 inches in diameter. With a view to ensure perfect stability, a wrought-iron tie runs below the level of the rails across the platform, consisting of a $\frac{5}{8}$-inch plate, riveted on to the bottom flange of one of the wrought-iron main-floor girders of the platform. The roof was erected by means of a travelling stage dividing the span into three parts, the side stages consisting of five, and the centre of six divisions each, and from back to front there were four divisions in each stage. The first staging travelled on 123 wheels 2 feet 8 inches diameter, running on a beam of timber 18 inches square, and was worked at the north end of the station towards the main

Fig. 40.



road, but after a few of the main ribs had been fixed in position, it was found necessary, in order to complete the roof by the required time, to erect a similar staging about the centre of the station, which was also to travel in the same direction. The horizontal transverse pieces in each stage were 12 inches by 6 inches, except the bottom pieces, upon which rested iron shoes to receive the feet of the standards, 12 inches by 12 inches. These lower horizontals were also 12 inches by 12 inches. Each main rib was supported by the staging until the wind-ties were finally fixed, and the latter staging was so constructed that trains might pass under it into the station before the completion of the work. The roof is glazed on the ridge-and-furrow principle, and cost 31*l.* 10*s.* per square (see Plates Nos. 53 to 56). It was designed for the Midland Railway Company by Mr. W. H. Barlow.

The St. Enoch Station, Glasgow, is covered with an arched roof of somewhat similar construction (see Figure 41); but here the main rib consists of a curve of five centres, struck with three radii, 40 feet at the springing, 125 feet at the middle of each side, and 90 feet carried over the centre. The clear span is 198 feet, and the rise 80 feet from the soffit of the rib to the level of the platform. The roof is 518 feet 3 inches long, divided into thirteen bays of 36 feet 10 inches, one of 24 feet,

9 inches, and one of 14 feet 8 inches. The principals are 5 feet deep all round, and are secured at the foot of each rib to a base-plate, which is carried under the platform for about 13 feet, and projects externally 1 foot 9 inches from the outside of the principal, the whole being firmly anchored down by 2¼-inch bolts. The principals are connected by purlins supporting four intermediate ribs, and the whole is braced diagonally by wind-ties. The end principal is filled in to serve as a wind screen, but is arranged differently to that at St. Pancras Station. In St. Enoch's Station there is no girder across the span, but the gable is trussed and bracketed firmly to the purlins, the lower portion being curved, and rising 33 feet 9 inches above the level of the platform. The wind pressure on the screen is thus transmitted to the purlins. The station forms the terminus of the Glasgow and South-Western Railway, the consulting engineer being Mr. A. Galloway (see Plate No. 57). The roof over the Central Station, Manchester, is very similar to St. Enoch's, but wider, being 210 feet clear span, with a rise from springing level to the crown of 84 feet 10 inches (see Figure 42). The principal is composed of five centres struck with three radii of 53 feet 3 inches, 143 feet 9 inches, and 91 feet 6 inches respectively. The principals are 35 feet apart, dividing the roof into sixteen bays, and the feet of the principals are anchored down to masonry foundations. There are four intermediate ribs, except in the end bays, where an additional main rib is substituted for the last intermediate rib, and the gable screen is made more like St. Pancras Station than St. Enoch's Station. The principals are connected by purlins and diagonal bracing, forming wind-ties, and the whole work was designed and carried out by Mr. L. H. Moorsom, to the satisfaction of the engineers of the Midland, Great Northern, and Manchester Sheffield and Lincolnshire railways (see Plate No. 11). The Drill Hall at Derby is built on a similar principle, without any direct tie, the form of the arch, together with the purlin connections and diagonal bracing, being sufficient to render the construction rigid and independent of the side walls (see Figure 43). There are nine wrought-iron ribs, 75 feet span, each 2 feet deep, placed 15 feet apart, and the level of the crown of the arch is 30 feet above the ground. The ribs spring from the ground, the lower portion being made of cast iron, and the side walls are built in between these standards. The wind-ties are of T section, running

Fig. 41.

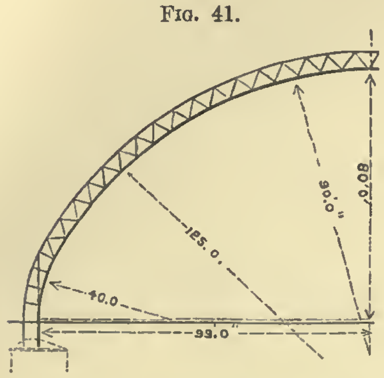


Fig. 42.

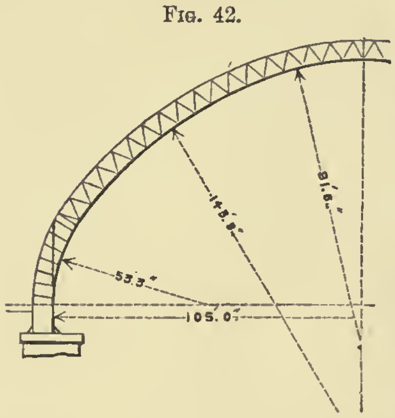
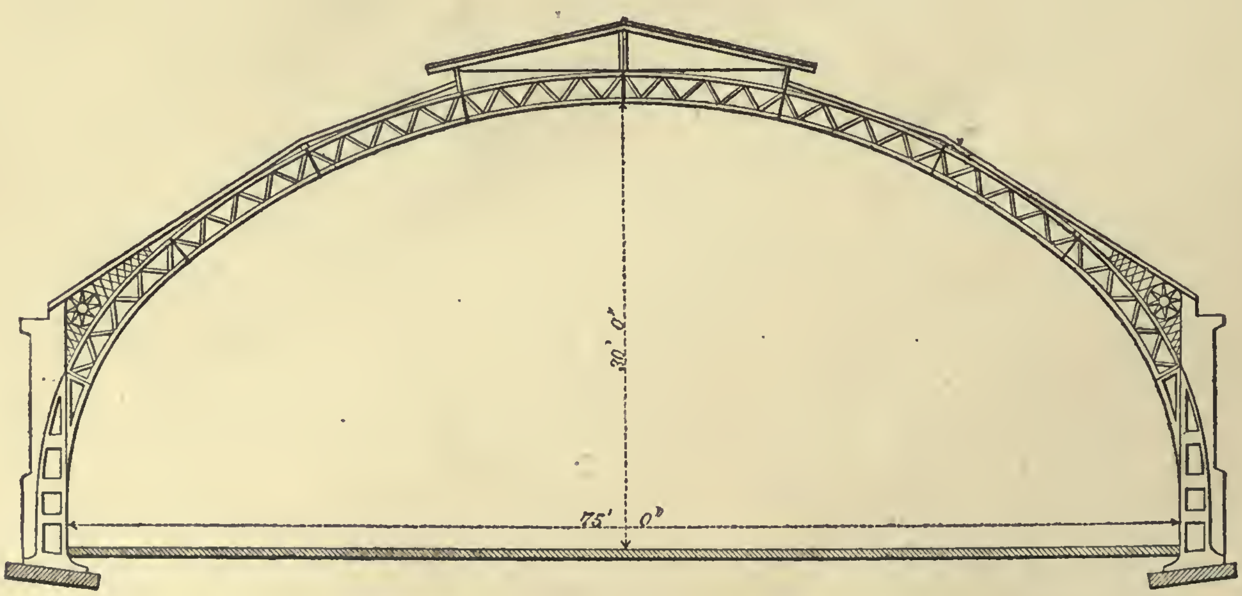


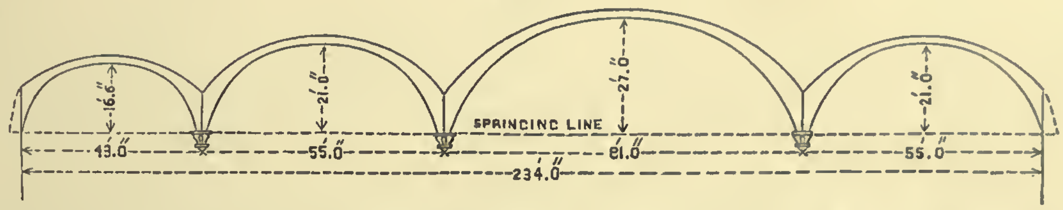
Fig. 43.



diagonally under the roof covering from the springing of each alternate rib to the crown of the arch three bays distant, crossing the intermediate ribs at the purlin connections.

The York Station belonging to the North-Eastern Railway (see Figure 44) is 234 feet in width between side walls, and is divided into four spans consisting of two arches of 55 feet span, having a rise of 21 feet above the springing level, one arch of 81 feet span with a rise of 27 feet, and another of 43 feet span with a rise of 16 feet 6 inches, meeting over columns placed 30 feet apart, the columns being connected by spandrel girders which carry two intermediate ribs similar in construction to the main ribs, placed 10 feet apart, there being no secondary ribs employed. The upper portion of the roof is glazed on the ridge-and-furrow system, carried on stiffeners placed between and attached to the principals, the lower portion being connected by purlins carrying the covering. The length of the roof is 795 feet. The roof is built on a curve in plan, the centre line

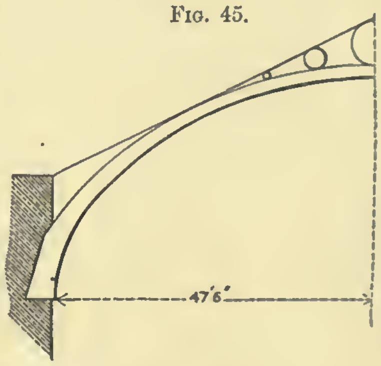
Fig. 44.



of the main roof of 81 feet span having a radius of 1131 feet 6 inches, or about 17¼ chains. The cost of the ironwork in the roof and foundations was about 56,000*l.*, or about 30*l.* 2*s.* per square (see Plate No. 58, and General View on Frontispiece).

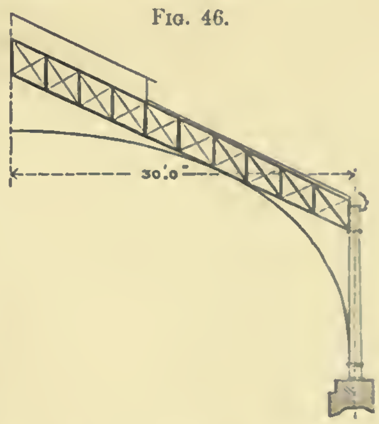
The question of the advisability of large or small spans has already been alluded to, but it may here be noted, in comparing the roofs of the St. Pancras Station (Midland Railway), the Victoria Station (London Chatham and Dover Railway), the Paddington Station (Great Western Railway), and the York Station (North-Eastern Railway), we have a series of roofs of practically the same total width, but having one, two, three, and four spans respectively. In the case of a roof built over a railway upon a curve in plan, as at York Station, the adoption of a single span is to be preferred, as it is difficult for the guards in charge of the train to see from one end to the other, or to observe the signals when columns intervene.

Fig. 45.



The Sunderland Station belonging to the North-Eastern Railway is covered with a roof constructed of principals similar to those in York Station, but the glazing is differently arranged (see Figure 45.) The principals are arched ribs of 95 feet span, with a clear headway in the centre of 45 feet 6 inches above the rail level. There are 48 ribs placed 10 feet apart and connected by purlins. The ridge is raised about 9 feet 6 inches above the bottom flange of the arch at the crown to carry the rafters which run down on each side in a straight line to the gutters resting on the side walls, which are raised at the abutments to meet them. The upper portion is glazed, and curved glazing is thus avoided. The outside lower portion is slated, while the interior view shows curved boarding carried on the main ribs.

Fig. 46.

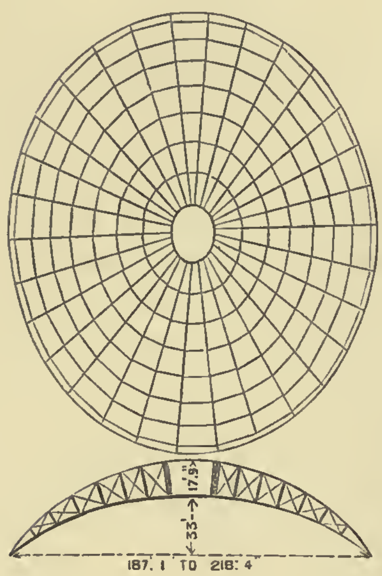


The Winter Garden at Torquay (see Figure 46), designed by Mr. Am-Ende, was erected in 1880, and consists of a central pavilion 60 feet square, with two transepts serving as entrance halls to the pavilion, and two wings, each 96 feet long, roofed over with principals of 60 feet span placed 12 feet apart, and formed of lattice girders strengthened with elliptical wrought-iron arches having cast ornamental spandrels, the whole being connected together to act as an arch. Each wing and transept terminates in a gable constructed of cast-iron framework. The slope of the roof is 1 in 2, and Z-shaped purlins formed of angle irons are placed 3 feet apart in plan, to which are fixed wooden purlins grooved on top, the grooves containing small zinc gutters. This roof is glazed upon a system patented by Mr. J. Watson, of Torquay, in which the sash bars do not project above the surface of the glass; but at convenient distances, or over the principals of the roof,

timbers are laid in a direction parallel with the sash bars, and made to project above the surface of the glass so as to form supports for planks in case of necessary repair. The glass is laid without lap lengthways, a clear space of $\frac{1}{8}$ inch being left upon the sash bars, while crossways the usual lap over the purlins is allowed. The corners of the four panes meeting at the intersection of the zinc gutters with the laps are held down by a galvanised bolt and india-rubber washer.

The roof over the reading-room at the British Museum consists of a dome 140 feet in diameter, formed of twenty iron ribs springing from the base and united at the top by a circular ring surmounted by a lantern 40 feet in diameter. The main ribs, 106 feet in height, are filled in with brick arches, and are supported upon twenty iron piers built into brickwork, each having a bearing surface of 10 square feet, including the casing, or 200 feet in all. The form of the roof was the original idea of Mr.—afterwards Sir—Anthony Panizzi, then principal librarian of the British Museum; the details being worked out by the late Mr. Sydney Smirke, the architect to the trustees, who was assisted in his design by Mr. Fielder, of the late firm of Messrs. Baker and Fielder, builders. The excellent ventilating arrangements were carried out by Messrs. Haden and Son, of Trowbridge, Wiltshire, and the building was completed in 1857.

Fig. 47.

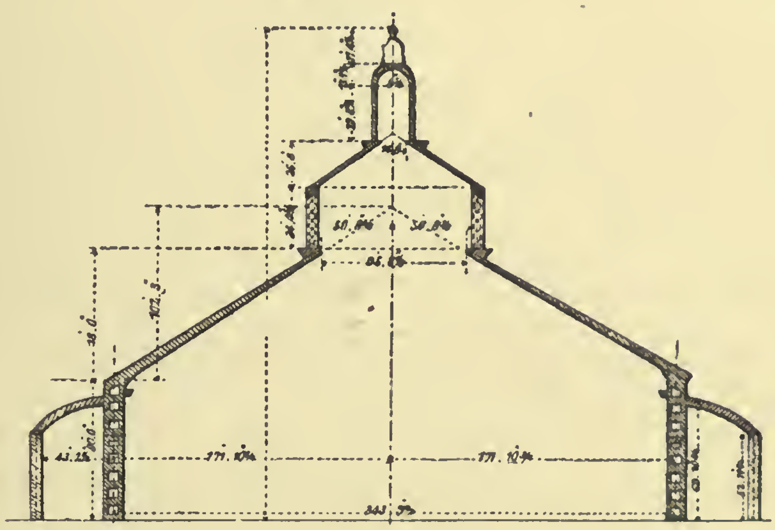


The roof over the Albert Hall is dome-shaped (see Figure 47). The plan of the building is nearly a true ellipse, and the plan of the roof is 219 feet 4 inches by 185 feet 4 inches. The principle adopted has been the construction of a continuous wrought-iron curb, resting on the top of the wall, about 120 feet high from the level of the Kensington Road. This curb may best be described as a flanged girder laid down on its side, upon which cast-iron shoes are secured by keys, from which the main curved ribs, thirty in number, spring, and in the centre of the roof another rigid curb has been formed, to which are fastened the top extremities of the main ribs. The top of the lantern surmounting the roof is about 150 feet above the floor level. Each truss-rod is formed of two pieces, these pieces being coupled together by an adjusting nut, 1 foot in length, to regulate the length of the rod. At the heel of the principal, the top and bottom members of the ribs meet, and are formed into one piece by means of a cover plate stiffened with angle irons. The central curb is also elliptical, and corresponds with the curves of the outer wall-plate. This curb is 17 feet $6\frac{1}{2}$ inches in depth, which corresponds to the maximum depth of the rib. It is a double ring, the top 2 feet 6 inches deep, and the upper part is formed of two girders; the outer one, 9 inches deep, is made up of a web plate and angle iron; the inner one is 1 foot 7 inches deep, the top member being on the same level as the outer ring, while the web extends 10 inches lower, forming a curb, against which the upper chord of the main rib abuts and is bolted. A plate $\frac{1}{2}$ inch thick and 2 feet 9 inches wide connects these inner and outer girders, and, overlying the top of the principals, ties them together with each other and with the curb. The construction of the bottom member of the curb differs from the top. It consists of a $\frac{1}{2}$-inch web plate, which is riveted to the under side of the lower chord of the principals, and stiffened with a flange on the inner side 8 inches deep and $\frac{1}{2}$ inch thick, the web being also strengthened with two T irons 6 inches by 8 inches by $\frac{5}{8}$ inch. The space of 17 feet $6\frac{1}{2}$ inches between the top and bottom portions of the curb is filled with vertical struts of plate and angle irons, and diagonal struts 3 inches wide by $\frac{3}{8}$ inch thick. The ribs radiate from the centre of the figure, and the ironwork is so arranged that the curved principals are capable of carrying their own weight, together with the weight of seven rows of purlins, between them and the rafters of the roof and ceiling. The thrust thus produced on the main ribs is taken by the curved ring forming the wall plate, while the strains on these ribs can be adjusted by means of wedges between the wall plate and the foot of each rib, by the slackening or tightening of which the whole of the outward thrust is brought to bear upon these curved ties, resting on the wall. The top flange of the rib acting as an arch, communicates the strains

produced under every variety of loading, pressure of wind, snow, &c. The wall plates and ribs are retained in their position by means of the curved ties in the principals and bracing. The engineers for this roof were Mr. J. W. Grover and Mr. R. M. Ordish, the main building being designed by Colonel Scott (see Plates Nos. 59 and 60).

Another example of an iron roof in which the thrust is provided for in a somewhat similiar manner is that designed by the late Mr. J. Scott Russell in the year 1873, for the Vienna Exhibition building. The roof, as shown in the diagram (Figure 48), resembles a cone with sides inclined at an angle of 30° to the horizon, and a base of about 345 feet supported on columns placed 36 feet apart, standing 80 feet above the ground. It is formed entirely of iron plates, which taper uniformly from

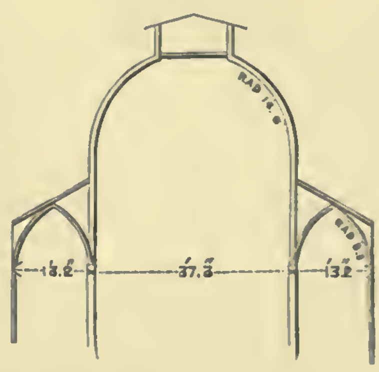
Fig. 48.



the circular base to the apex of the cone and are riveted together. The lower edge is strengthened and supported by a heavy wrought-iron curb or continuous circular box-girder. The upper portion of the cone is removed, leaving an opening 100 feet in diameter, over which is placed another conical dome, standing on a drum 34 feet high. On the top of this again is a third dome or lantern, 24 feet in diameter, placed on a drum 28 feet high. To prevent any tendency of the plates to sag between the upper and lower horizontal wings, the entire structure is stiffened with girders running from curb to curb, while to prevent distortion in any other way ring girders at right-angles to the rafter girders are fixed round the roof. All these girders are placed outside the roof instead of inside. The total elevation is about 280 feet. These forms of construction (Figures 47 and 48) present great strength, there being no outward thrust on the supports, whilst their resistance to crushing is considerable, and great savings both of material and consequent pressure on the foundations are effected.

The roof over the Winter Garden of the Leeds Infirmary, erected in 1868 (see Figure 49), presents the appearance of being constructed on the principle of an arch, but is, strictly speaking, on the principle of a dome. The internal dimensions of this structure are 151 feet by 63 feet 6 inches. The infirmary walls surrounding the Winter Garden do not sustain any portion of the outward thrust. The main roof is carried by the four corner rafters or hip ribs, which having thus to perform the chief portion of the work, are constructed stronger than the ordinary ribs. The roof is carried on twelve columns 32 feet high by 24 feet 10 inches apart, six on each side of the building, leaving a space of 37 feet 3 inches between the rows, and an aisle on each side 13 feet 1½ inch wide. From these columns spring ornamental spandrels to a lower frame of lattice girders connecting the tops of the columns firmly together, and forming a rectangle in plan 124 feet 2 inches by 37 feet 3 inches. At each column similar spandrels to those forming the arches between the columns are placed

Fig. 49.

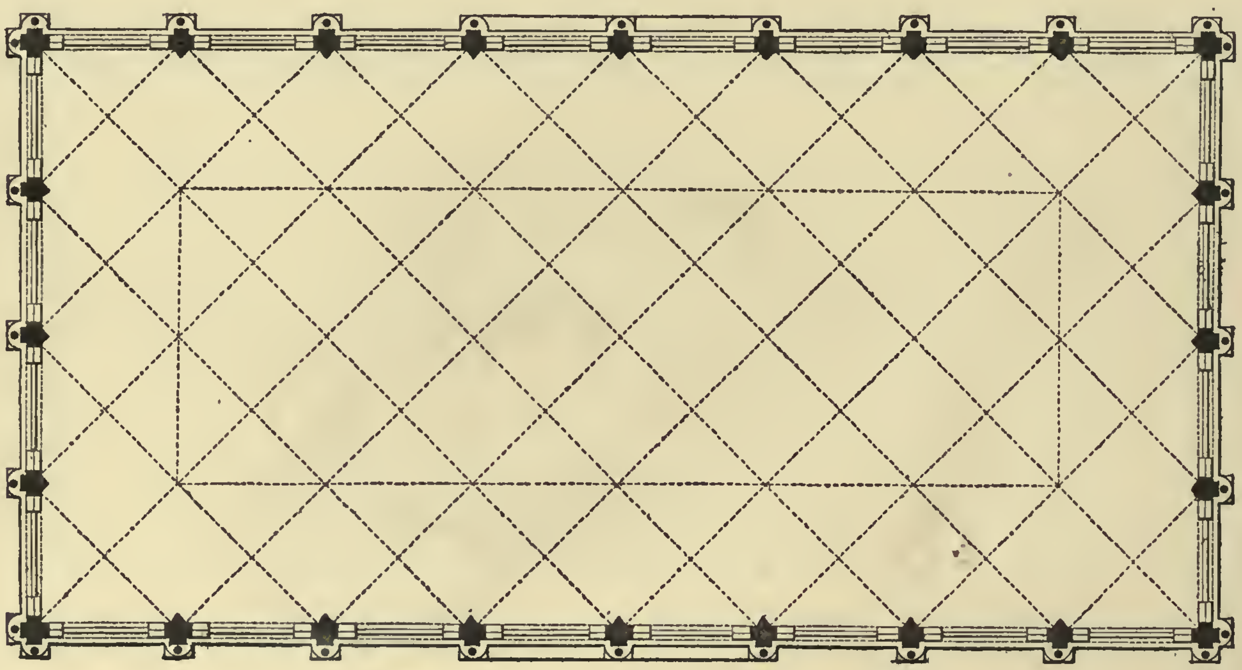


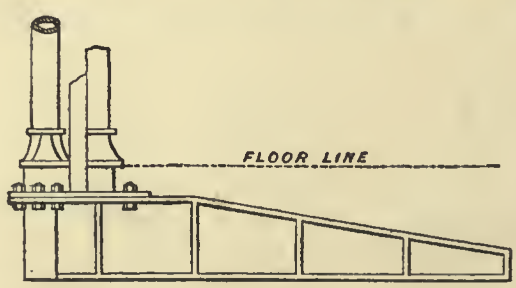
over the side aisles, and are surmounted by cast-iron rafters with perforated webs inclined at an angle of 30° from the brick wall of the infirmary to the level of the top of the columns. The

main arched ribs are also of cast iron with perforated webs, and are bolted to this bottom frame of lattice girders, and at the top to a similar rectangular frame 99 feet 4 inches by 12 feet 5 inches. This top frame is braced by cross pieces of cast iron 12 feet 5 inches apart, and is thus rendered exceedingly rigid. The weight of the upper frame, as well as the weight of the greater part of the lower roof, is transmitted to the corner ribs, which, in return transmit a horizontal thrust upon the upper frame. The lower frame, acting as a tie, has now to receive this horizontal strain on the bottom of the ribs. The load on the intermediate ribs, although producing no outward thrust, is sustained partly by the corner ribs, partly by the upper and lower lattice girders, and partly by the intermediate columns. Both tiers of girders are 5 feet deep, and the vertical distance between them is about 15 feet 2 inches. There are two rows of cast-iron purlins connecting the main ribs, and a single row between the aisle rafters, half-way between their extremities. Two rows of moulded cast-iron gutters are fixed at the base of the arch-pieces or spandrels at their junction with the lower girders, and also above the aisle rafters against the brickwork forming the walls of the central hall. The summit of the ridge-piece is 60 feet $6\frac{1}{4}$ inches above the floor level. Exclusive of glazing, the cost of this hall was about 31*l.* 6*s.* per square. The whole of the construction of this iron building was designed by Mr. R. M. Ordish, and approved by the late Professor G. Gilbert Scott, the architect of the infirmary building (see Plates Nos. 29 to 31).

Generally speaking, the hips of a roof over a rectangular area are of special construction, but by making the ribs spring diagonally over the space to be covered and at equal distances apart, they will by their intersection divide the entire central area into equal squares, and thus make the hip ends the same as the sides and similar all round the roof. This plan was adopted in the building of a kiosk for India made entirely of cast iron (see Figure 50). The ribs were supported on columns placed 10 feet apart round the exterior of the structure, which was 80 feet long, 40 feet wide, and

Fig. 50.



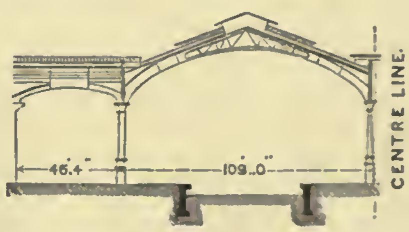


42 feet high in the centre. The base of each column was attached by bolts to a girder running inwards for a distance of 10 feet beneath the floor level, thus enabling each column to resist the tendency of turning, under the influence of strain produced by the load on the roof. A considerable

amount of ornamental effect was aimed at, and secured, in this design. Another good example of cast ironwork as adapted to roofing is to be found in the Santiago Market, designed by Mr. C. H. Driver, architect, and Mr. Edward Woods, civil engineer. The building occupies a rectangular space, surrounded by a low corridor, which separates it from a one-storied building. The market is divided into nine squares, over which are constructed separate roofs carried on columns and girders. The central roof is the highest, and is surmounted by a dome. The roofs over the four squares at the angles are less in height than the central one, and the roofs over the middle squares along each side are at a lower level again. Each roof is hipped each way, and their varying height enables their louvred faces to be well exposed to the air. The new Central Fruit and Vegetable Market now in course of construction, designed by Mr. Horace Jones, the City architect, is situated at the junction of Charterhouse Street with Farringdon Road. This site is likewise divided into nine squares by sixteen columns placed at the angles of the squares, and connected at the top by girders which carry the roofing. The roofs over the outside squares are of timber, with clear spans of 47 feet 6 inches and 56 feet respectively. The girders forming the centre square are united at the corners by girders of the same depth, 22 feet in length, so as to form an octagon in plan, measuring 25 feet parallel to the columns. The roof consists of eight wrought-iron ribs springing from the angles with a rise of 22 feet 6 inches, and united at the top by an octagonal ring measuring 10 feet 3 inches, parallel to the line of columns, and 9 feet at the angles. Wrought-iron purlins are placed round the dome, the construction forming a rigid skeleton of ironwork, which is filled in with ornamental woodwork, and fitted with eight large glass louvres, affording an ample amount of ventilation, so essential for a market of this description, while at the same time the building is well lighted without admitting the glare of the sun.

The area occupied by the various lines and platforms in the terminus station of the Great Eastern Railway at Liverpool Street (see Figure 51) is covered with a roof in four spans, the two central ones being 109 feet each, and the side spans 46 feet 4 inches and 44 feet 8 inches respectively. The central spans each consist of two cantilevers supporting a girder similar to the truss shown in Figure 8, but with the diagonals placed in the opposite direction, that is, with their top ends pointing towards the centre of the span. The principals over each span are secured to each other over the supports, and form a continuous girder anchored down at the ends by the arches forming the wall, as well as by bolts built into the brickwork. Cast-iron columns form the supports at the junction of the roofs, and are placed double in the centre at the meeting of the two main spans on account of the extra weight to be sustained at this point compared with that at the junction with the side spans. The centre columns are placed 5 feet apart transversely, so as to reduce the strains on one span caused by unequal loading on the other. The columns act as rain-water pipes to drain the roof, and are placed 30 feet apart under each principal longitudinally. The main ribs are connected by trussed purlins divided into three bays, and glazed upon the ridge-and-furrow system, resting upon the diagonal bars of the truss, and the whole roof is further stiffened by special spandrel castings springing from column to column between the principals. A transept is formed in one part of the roof, where it was required to place the columns as far apart as possible, and diagonal ribs intersecting each other, similar in construction to the transverse principals, are here introduced, together with a special principal between the spans, by which means a clear space of 90 feet between the columns longitudinally is obtained, and thus great lateral stiffness given to the whole structure. The roof was designed by the late Mr. Edward Wilson. At the Charing Cross Station of the South-Eastern Railway the central three bays of the upper portion of the gable screen are left open. In the Liverpool Street Station roof of the Great Eastern Railway the screen is omitted altogether (see Plates Nos. 61 to 64). The roof over the Aldgate Station of the Metropolitan Railway is constructed of principals somewhat similar in construction to the centre span of the roof last described, but wholly of wrought iron. The principals divide the roof into six bays or spaces of 18 feet each, and are 82 feet 4½ inches span. The roof over the new

Fig. 51.



railway station at Brighton consists of four spans supported on columns. The centre line of the station has a radius on plan of 1148 feet, and the spans taper from one end to the other. The principal spans resemble those last described, and are formed of upper straight rafters having a slope of 1 in 2, with a lower curved rib and lattice web. One span tapers from 106 feet to 117 feet, the 106 feet span having a rise of 24 feet from the intrados of the arch to the springing level, and the other main span tapers from 98 feet to 75 feet, the 98 feet span having a rise of 23 feet above the springing level to the intrados of the arch. The principals are placed 25 feet apart, and the supporting columns are connected by spandrel girders carrying three intermediate ribs in each bay. The main principals are bolted firmly together and attached rigidly to a raised portion of the column, both in the centre of the station and also to the side spans, which vary in width, their maximum dimensions being 46 feet on one side and 38 feet on the other. With the object of relieving the side spans of thrust from the main roof, light tie-rods with a central sling rod are attached to the main principals. This work was designed and erected under the superintendence of Mr. Henry E. Wallis, subject to the approval of Mr. F. D. Bannister, the engineer to the London Brighton and South Coast Railway Company.

There are occasions in an Engineer's practice when roofs have to be lifted while the traffic beneath must go on uninterruptedly. Such was the case at the Euston Station of the London and North-Western Railway Company, which, owing to increased traffic, was found deficient in ventilation, and was raised about 6 feet by the aid of some forty powerful screw-jacks. Some of the jacks were afterwards used in lifting the eastern goods' shed roof of the Great Northern Railway Company.

In the Canterbury Music Hall, Westminster Bridge Road, novel arrangements have been adopted to insure free circulation of air. The open central space over the pit is 36 feet long by 18 feet wide, fitted with a special movable covering, which slides laterally in one piece (see Figure 52). The side walls of the building are connected by main girders united by transverse girders, which are likewise attached to other girders running at right angles to them and parallel to the main girders, the whole framework being firmly braced together by diagonal ties, forming a very rigid and strong construction. The sliding portion rests on a continuous line of rails 37 feet apart, fixed to the longitudinal bearers attached to all the transverse girders. Such an arrangement enables the interior to be speedily freed from all vitiated air, and would prove of advantage in the event of fire, enabling firemen the more readily to direct the hose to the parts most affected. The plan was the invention of Mr. Robert Edwin Villiers, the late manager (patent, A.D. 1877, No. 4581). The work was completed in 1876. In the hall of the Circus at Paris the same idea has been carried out on a larger scale (see Figure 53). The central space over the arena is surmounted with a special movable covering, 177 feet long by 57 feet wide, which divides into two equal parts longitudinally, each resting on wheels, so as to be pulled aside right and left, when the weather permits, on outside girders, and thus completely to disappear from the audience inside. The fixed

Fig. 52.

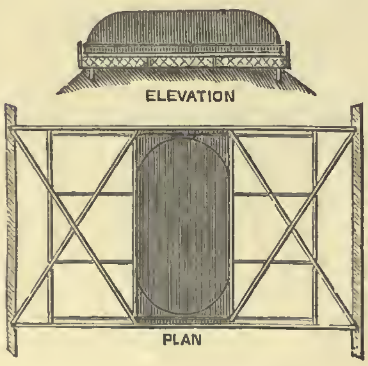


Fig. 53.

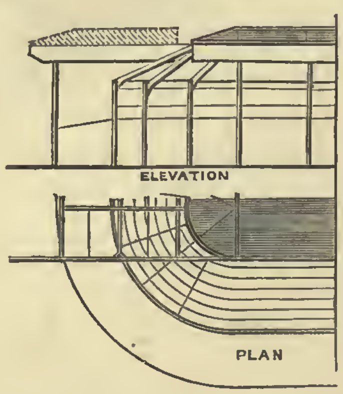
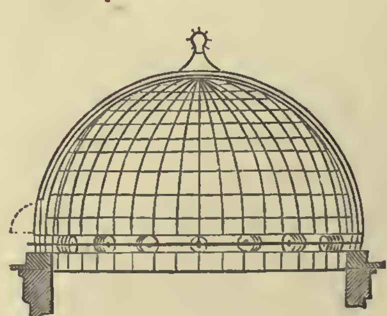


Fig. 54.



roofing which surrounds the space closed by the sliding portion is supported on columns. The hall was built in 1877, under the direction of Mr. E. Lantrac, the engineer to the Circus Company, by whom the work was designed.

Another example of an opening roof exists in the Royal Observatory of Vienna, designed by

Mr. F. Fillner, architect. In this case a dome (see Figure 53) 45 feet in diameter is constructed to revolve, and by means of special gearing a clear opening provided in the roof by raising up a shutter one side and lowering it the other. The dome is formed of two thin shells of steel plates, varying in thickness from No. 16 to No. 18 B.W.G., riveted on the inside and outside of light steel plate girders 9 inches deep at the crown and 18 inches at the base, which is stiffened sufficiently to bear the varying strains as the dome revolves without producing outward thrust. The revolving arrangements were designed by Mr. Howard Grubb, Honorary Master of Engineering in the University of Dublin. They consist of twenty sets of three rollers fastened rigidly together and connected neither to the dome nor the walls. The foot-plate of the dome is made with a projecting rib, which travels on the centre roller, without bearing on the side rollers, and the side rollers travel on a special bed-plate secured to the wall, and provided with two projecting ribs, which serve as rails to carry them. The faces of these upper and lower projecting ribs, on which the rollers revolve, are not parallel, but are planed so as to converge accurately to the centre of the dome. The rollers are turned true to fit these ribs, and the inner roller is grooved to direct them in turning round. Sliding friction is thus practically reduced to zero, and a kind of "live ring" is formed moving at half the speed of the dome. The rollers are placed at a sufficient distance apart to maintain lateral stiffness in the ring, while the dome is prevented from slipping by an independent set of guide rollers, supported on brackets descending from the dome, and bearing against a ring made to slide true round the cast-iron wall-plate. Any alteration of form in the dome can be provided for without interfering with the supporting system, by adjusting the lateral rollers, which always have a true circle to play against so long as the wall holds, and the construction of the dome commends itself as giving maximum stiffness with a minimum amount of material, in addition to the advantage of the temperature inside being uniform with the outside when the dome is closed.

All iron exposed to the air is more or less sensitive to corrosion and consequent decay. This may be delayed by galvanising the iron, or covering it with a thin coating of zinc; but the process of galvanising is considered to render the iron brittle. Many attempts have been made to protect iron surfaces by the application of various kinds of paint or varnish, but some coatings, unless they adhere chemically to the surface, are liable to scale off or perish in a variety of ways. Even when the coating is generally well painted, the smallest flaw in the continuity of the covering will give entrance for the weather or any corrosive vapours or liquid to which the structure may be subject, to exert an injurious effect; for the rust from the exposed spot will spread laterally under the coating, and be all the more dangerous and destructive from being partly concealed from view. When the rust is thrown off the paint comes off with it. Professor Barff's method of protecting the surface consists in placing wrought iron and steel under the influence of superheated steam at a sufficiently high temperature to decompose the steam and allow its oxygen to attack the iron or steel, whereby a hard coating of magnetic oxide is formed upon its surface, which is less affected by atmospheric conditions than any other covering. The working of the process has been improved upon in the Bower-Barff method, by means of which not only wrought iron and steel but cast iron can all be treated in the same furnace and rendered rustless with equal permanency and expedition. The process is of recent introduction, but gives fair promise of success, being simple in application and comparatively inexpensive. The iron is placed in a fire-brick chamber, connected with which is a set of gas producers; but before admitting the gas it is led along passages and mixed with air in a highly heated condition, forming carbonic acid, which, with a small quantity of free air, is allowed to enter the chamber and become partially divested of oxygen by contact with the heated material. It is necessary to limit the quantity of air admitted, as an excess causes a film of the sesquioxide of iron (Fe_2O_3) to be formed over the coating of the magnetic oxide (Fe_3O_4). The air is heated in the chamber by passing over a fireclay regenerator, both for the purpose of combustion and also for oxidation. The sesquioxide of iron can be reduced by closing the air valve and letting carbonic oxide into the chamber. Rusty iron may be similarly treated. The system, however, is unsuitable for coating metal subjected to straining, as the coating peels off under pressure in the case of wrought iron and steel, but answers very well for cast iron. Anti-corrosive paints are less efficacious, and paint only serves for purposes of decoration and subsequent

preservation. In the opinion of the author, oiling is a very much better protection from the effects of the weather or the action of steam than painting, but care is needed properly to clean off the black scale or oxide formed upon the iron by contact with the air immediately after leaving the rolls. In Holland great attention is paid to these details, the specifications of the engineers minutely describing how the iron is to be treated before the oil and paint are applied. After being properly cut, punched, or otherwise finished off in the shops, each piece before being fastened to any other piece is made quite free from rust and scales by immersion in a bath of dilute muriatic acid, and kept there as long as the inspecting engineer thinks proper. It is then lifted out by means of iron hooks and brushed with water, which removes all the black scale. Immediately afterwards it is immersed in a bath of fresh lime water, and then placed in a bath of boiling water, where it must remain till it is about as hot as the water. The water is renewed directly any traces of acid are discovered in the water bath. After being thus washed, the iron is removed from the hot-water bath and allowed to dry, but before becoming quite dry, while still warm it is besmeared abundantly with hot linseed oil, and then receives the first coat of paint. All rivet heads are similarly covered with hot linseed oil and painted over after the plates or other pieces are riveted up. A second coat of paint is given to the iron before it is placed in contact with other pieces of different material, and while all parts are accessible to the painter's brush, care being taken that the pieces so painted are perfectly dry, and that the weather is not damp at the time the second coat of paint is applied. The paint used consists of lead or iron minium well mixed with boiled linseed oil. Iron minium, consisting of iron oxide with a small portion of clay and water, is cheaper and more used than lead minium.

In the erection of roofs, it is necessary to take care not to create any initial strain upon the various portions greater than they are calculated to bear, and this precaution is especially necessary to observe with purlins. It is also essential in all riveted work to observe that the rivet holes are carefully marked and accurately punched or drilled, so as to secure the precise correspondence of all rivet holes through any number of plates or bars and the exact fitting of the rivets within such holes, as in the narrow bar usually employed in roof constructions the stability of the structure is likely to become endangered by errors of workmanship.

It must also be observed that all sections of material employed are of the exact dimensions shown upon the drawings. When the iron is required to be cranked or bent for knees, laps, or otherwise, this must be executed with the greatest care and with easy curves so as to avoid any abrupt bend or square shoulder. For all roofs up to 60 feet span, the author prefers the use of flat riveted connections to forged ends welded on to round rods, as the percentage of loss due to punching is greater in small bars than in large ones. The loss of strength with the adoption of screwed ends according to the usual reduction of area by Whitworth's threads is likewise not to be forgotten in calculating the sectional area required.

The best plan to be adopted in fixing the glazing in a roof is much open to argument. The ridge-and-furrow system admits of easy access for repairs, but it is evident that where the ridge and furrow follow the curve or pitch of the roof, one side of the sash bar suffers more from the weather than the other, destroying the putty, whereas when the sash bars are parallel to the main transverse ribs, the water will run off the roof more freely. Whatever system of glazing is adopted, a glazier's tool should be used as little as possible in the erection of a roof, as it is easy to ascertain the usual sizes manufactured and to work them in accordingly. In the covering of the new roof over the King's Cross Station the putty used was that known as "thermo-plastic putty," manufactured by Sir W. A. Rose and Co., of Upper Thames Street, London; which with due care in preparation is found to harden in a few hours after it is used; but when exposed to solar heat sufficient to cause the expansion of the glass and metal, it is asserted to become plastic, and on cooling again to return to its original firmness. This method, though superior for outside work to the use of ordinary glaziers' putty, cannot rival the systems in which putty is avoided altogether, as in exposed situations, even with the use of the most approved putty, fractures and leakages are sure to occur. By the adoption of metallic sash bars in the non-putty systems great savings are effected in the periodical expenditure for painting and repairs, and time and labour in fixing are also economised.

Among the numerous methods employed for fixing glass with metal connections, independent of putty, the best arrangement (in the Author's opinion) is that made by Mr. T. W. Helliwell, of Brighouse, Yorkshire, consisting of a zinc or copper bar with double gutter (see Figures 59 and 60), on the top of which is screwed a zinc or copper cap for holding the glass down.

It will be observed, upon reference to the illustration, that there is free play allowed for expansion and contraction under the influence of variations of temperature. Circular as well as straight rafters can be successfully glazed upon this system (see Plate 67) with straight glass, and there is no rattle in high winds, as the glass is firmly held at the sides. There is also no drip, as ample provision is made for carrying off the condensed moisture, which ultimately falls outside the roof at the eaves; while the supporting bars being fixed in the direction of the slope of the roof, no impediment is presented to the free flow of water off the roof, as horizontal connections are dispensed with. Any portion of the glass can be easily removed when required to be cleaned from the action of the poisonous gases which deface the skylights of so many of our railway stations and manufactories, and the portion so removed can be replaced pane by pane in each bay after cleaning without erecting inside scaffolding. When necessary a broken pane can be easily reglazed, and the system is applicable to moderately flat as well as to steep inclinations. No air is admitted except such as is provided for, by special arrangements in the construction of the roof, which is the only true way to obtain proper ventilation. It is well for a semicircular arched roof to be surmounted by a continuous raised ridge from end to end, not only to act as a ventilator, but because the top of an arch is very flat, and if the roof is glazed all over, a better slope can be provided in the raised portion for throwing off the rain water.

Figures 61 to 63 (page 39) illustrate Mr. Helliwell's system of zinc roofing without solder or outside connections. In the old systems of laying zinc roofing, both screws and solder were used. Owing to the expansion and contraction of the zinc sheets, the solder is found to crack and the screws tear the sheets, thus causing leakage. In Helliwell's method true play is allowed in every direction, and thus not only is leakage avoided, but the buckling which is so frequently observed in old zinc roofs cannot happen. Sheets can, if preferred, be fixed without either wood rolls or zinc caps. Plate 67 illustrates both straight and circular rafters covered on this system.

Figure 55 (page 37) gives a plan of the Victoria Station belonging to the Lancashire and Yorkshire Railway Company in Manchester, and shows the form of trusses used to cover the station upon the south side. Figure 56 (page 38) shows the form of covering employed upon the north side. Girders 57 feet apart running north and south support trusses 10 feet apart running longitudinally east and west. To obviate the effects of the horizontal thrust from the arch, ties (as shown dotted in Figure 56) have been inserted in the two end bays at the west end of this roofing. Figure 57 shows the form of truss adopted by the London and North-Western Railway Company for the covering of their roof at the Exchange Station, Manchester, which is situated upon the west side of the Victoria Station. The diagram (Figure 57) gives the relative lengths of the various parts of the principal. There are 53 main ribs placed 11 feet 5 inches to 13 feet 1½ inches apart, together with two end gables, and between each main rib the covering is supported by light trussed purlins. The roof is in three spans of 62 feet 5 inches, 59 feet 5 inches, and 71 feet 8 inches respectively, and is supported upon the outside by walls and at the junction of spans by columns placed under every third principal, the two intermediate principals being supported by girders connected to the head of the columns.

The Tables given upon pages 78 to 80 show the amounts to be taken in estimating the fixed load upon a roof. Glass is sold by thickness, not by weight, but its weight is required in estimating the dead load upon a glazed roof. Rough plate-glass can be obtained in stock sheets from 120 inches by 40 inches to smaller sizes as required. Sheet lead is recommended to weigh 5 lb. per foot super. for aprons, 7 to 8 lb. per foot super. for roofs, flats, gutters, &c., and from 6 to 8 lb. for hips and ridges. Cumberland and Westmoreland slates vary a little from the Welsh slates in their covering capacity per ton, according to the quarries they may be taken from. Upon an average the best quality weigh 75 lb. per yard super., and second quality 90 lb. per yard super.

EXAMPLES OF FIFTY IRON ROOFS.

Name of Roof.	Order of Spans.	Length.	Total Width.	No. of Spans.	Maximum Single Span.	Distance apart of Principals.	Total Rise.	Rise of Tie-rod.	Depth of Principal.	Reference to Figures, Pages 1 to 31.
	ft.	ft. in.	ft. in.		ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
St. Pancras Station, M. R.	240	690 0	240 0	1	240 0	29 4	96 0	..	6 0	40
Blasgow, Contral Station	..	560 0	213 6	1	213 6	35 0	..	..	20 0	17
Birmingham, New Street Station ..	..	840 0	212 0	1	212 0	24 0	40 6	17 6	23 0	5
Liverpool, Lime Street Station (L. & N. W. R.)	..	645 0	403 0	2	212 0	32 0	44 9	22 0	22 9	11
Manchester, Central Station	200	550 0	210 0	1	210 0	35 0	84 10	..	5 3	42
Glasgow, St. Enoch Station (G. & S. W. R.)	..	518 3	198 0	1	198 0	36 10	78 9	..	5 0	41
Cannon Street Station, S. E. R. ..	..	653 0	190 4½	1	190 4½	33 6	60 0	30 0	30 0	5
Glasgow, Queen St. Station (N.B.R.)	..	415 0	170 0	1	170 0	41 6	46 0	14 9	31 3	29
Charing Cross Station, S. E. R. ..	..	490 0	166 0	1	166 0	35 0	45 0	25 0	20 0	5
Liverpool, Central Station	..	495 0	..	..	160 0	55 0	40 0	14 0	26 0	..
Carlisle Citadel Station	..	1002 6	279 0	2	154 6	40 6	..	..	15 0	18
Liverpool, Lime Street Station (old roof)	150	..	153 6	1	153 6	21 6	36 0	24 0	12 0	3
Exeter, St. David's Station (G. W. R.)	..	360 0	132 0	1	132 0	15 0	22 0	5 0	17 0	10
Victoria Station, L. C. & D. R. ..	..	385 0	256 4	2	129 0	35 0	31 6	8 6	23 0	..
Royal Agricultural Hall, London ..	..	400 0	220 0	3	125 0	24 0	51 0	..	3 4	35
Bristol Junction Station	..	500 0	125 0	1	125 0	18 9	31 3	10 5	20 10	14
Victoria Station, L. B. & S. C. R. ..	..	734 0	242 0	2	124 7	50 0	..	..	10 9	9
Paris Exhibition, 1878, Machinery Halls	..	2150 0	116 9	1	116 9	49 0	48 0	41 9	6 3	8
Glasgow, Bridge Street Station ..	..	600 0	163 0	2	114 0	31 6	..	..	12 0	16
Liverpool Street Station, G. E. R. ..	..	624 0	309 0	4	109 0	30 0	35 6	25 6	10 .0	51
King's Cross Station, G. N. R. ..	..	792 0	210 6	2	105 3	20 0	50 6	..	2 0	39
Paddington Station, G. W. R.	100	700 0	240 6	3	102 6	10 0	33 9	..	1 8	33
Birkenhead, Woodside Station ..	..	375 0	118 11	2	97 11	25 0	25 0	14 8	10 4	11
Edinburgh Drill Hall	..	135 0	97 6	1	97 6	13 6	27 0	13 6	13 6	12
Earl's Court Station	..	360 0	96 0	1	96 0	20 0	24 6	2 0	22 6	26
Broad Street Station, N. L. R. ..	..	460 9	190 0	2	95 0	36 10	17 0	4 6	12 6	28
Sunderland Station, N. E. R.	..	470 0	95 0	1	95 0	10 0	35 0	..	1 8	45
Birmingham, Snow Hill Station ..	..	506 0	150 3	2	92 0	22 0	27 6	18 6	9 0	3
Coventry Market	..	160 0	..	1	90 0	8 0	45 9	..	1 3	36
Manchester Skin Market	..	201 11	113 0	2	90 0	32 0	46 0	..	2 0	..
Leeds Station, N. E. R.	..	462 0	244 0	3	89 0	12 8½	28 6	9 0	19 6	23
London Bridge Station, L. B. & S. C. R.	..	660 0	266 0	3	88 0	16 0	27 0	9 0	18 0	5
Blackfriars Station, L. C. & D. R. ..	..	401 6	209 4	..	87 3	32 3	22 0	13 0	9 0	11
Paris Exhibition, 1878, Industrial Halls	..	..	82 0	1	82 0	16 4	17 0	1 8	15 4	1
York Station, N. E. R.	..	795 0	234 0	4	81 0	10 0	27 0	..	1 9	44
Sheffield Station, M. S. & L. R. ..	..	400 0	80 0	1	80 0	12 6	16 3	2 9	13 6	..
Westminster, Royal Aquarium ..	..	340 0	..	..	80 0	20 0	40 0	..	6 6	31
Alexandra Palace, Great Hall	..	..	79 2	1	79 2	25 0	39 7	..	1 10	38
Penzance Station, G. W. R.	..	250 0	77 0	1	77 0	15 7½	12 6	2 0	10 6	..
Middlesborough Station, N. E. R. ..	..	309 0	119 3	2	76 6	20 2½	44 0	..	2 0	37
Derby Drill Hall	..	150 0	75 0	1	75 0	15 0	30 0	..	2 0	43
Oban Station	..	270 0	..	..	71 6	30 0	..	..	7 10	19
Port Elizabeth Drill Hall	..	..	70 0	1	70 0	..	15 1	5 9	9 4	7
Tunbridge Wells Gasworks, Retort Houso	..	200 0	65 0	1	65 0	25 0	..	..	5 0	20
Swansea Station	..	..	70 0	2	64 6	20 0	16 0	1 0	15 0	6
Dublin Gasworks, Retort House ..	..	296 1	64 3	1	64 3	6 6	33 0	5 0	28 0	6
Perth Station	50	..	115 0	2	57 6	8 2½	11 6	2 3	9 3	6
Brazil, Nitheroy Gasworks	..	162 6	50 0	1	50 0	12 6	..	..	6 0	8
Millwall Docks, Grain Warehouses	..	211 0	924 0	21	44 0	15 0	8 9	nil.	8 9	24
Glasgow, Blythwoodholme Arcade ..	..	132 9	39 10	1	39 10	12 6	..	..	..	15

NOTE.—*For reference to Plates see Table of Contents.*

Fig. 55.

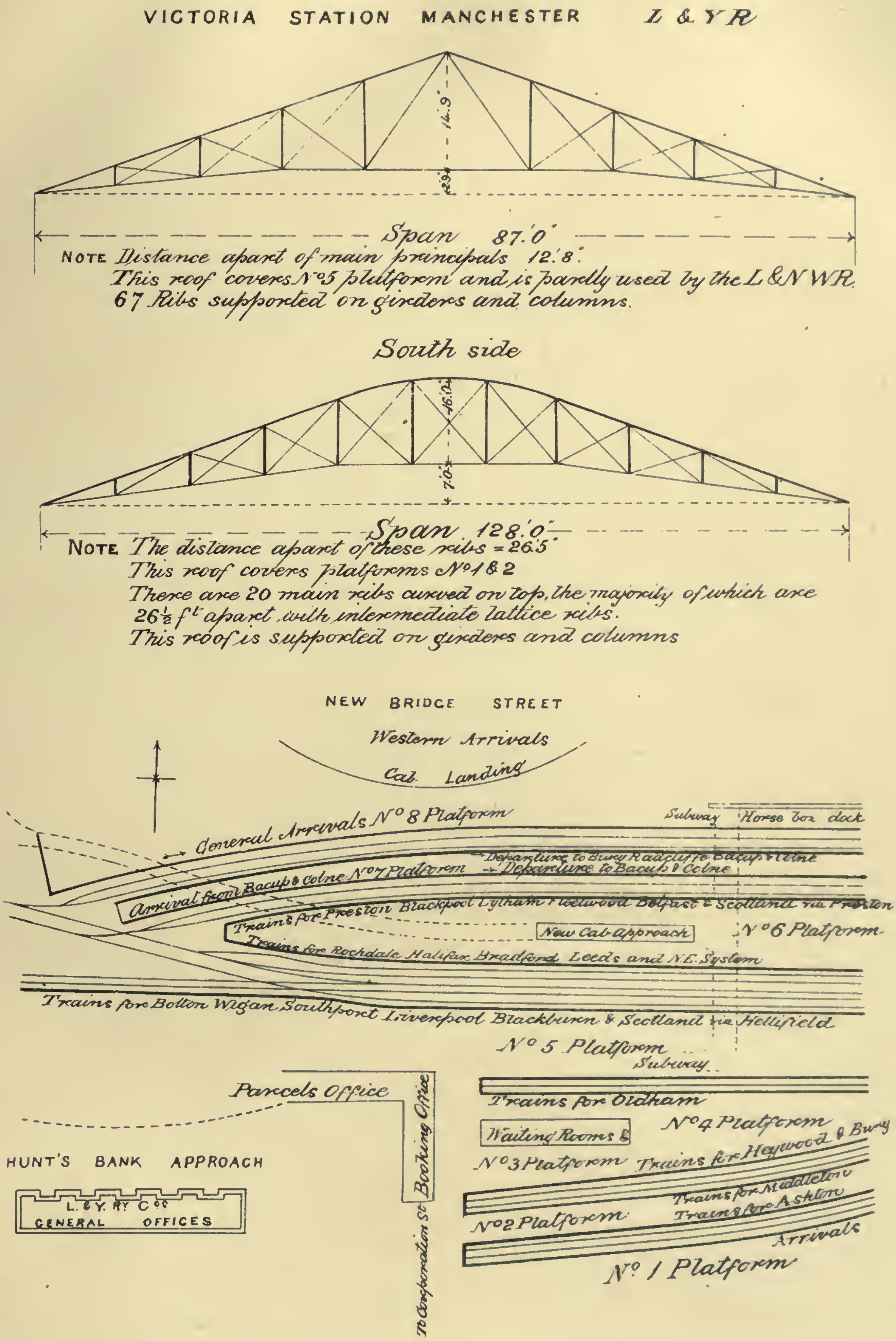


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Fig. 56. VICTORIA STATION MANCHESTER L. & Y. R.

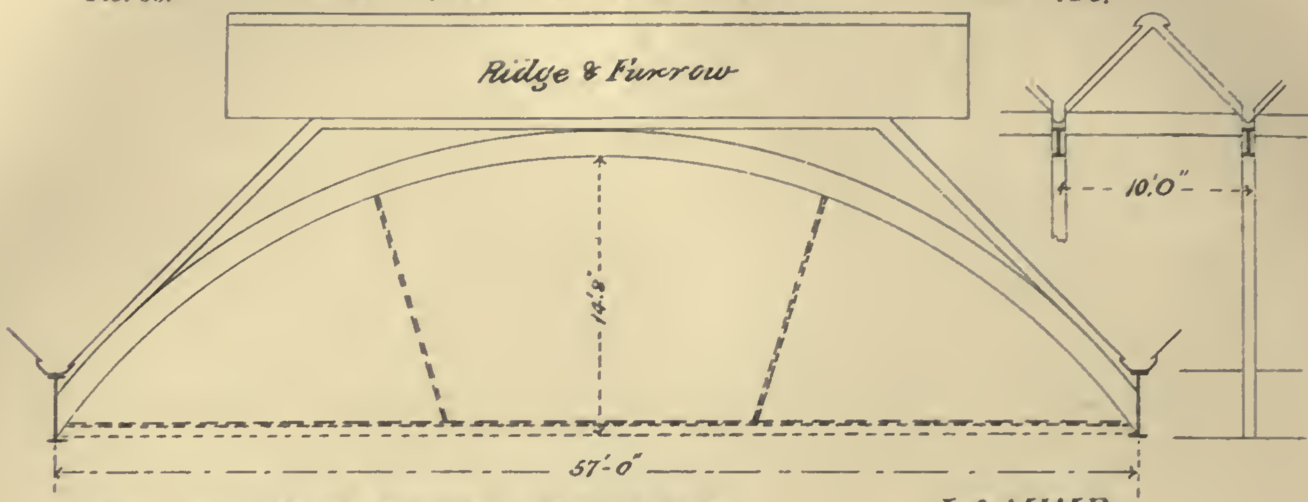


Fig. 57. EXCHANGE STATION MANCHESTER L. & N. W. R.

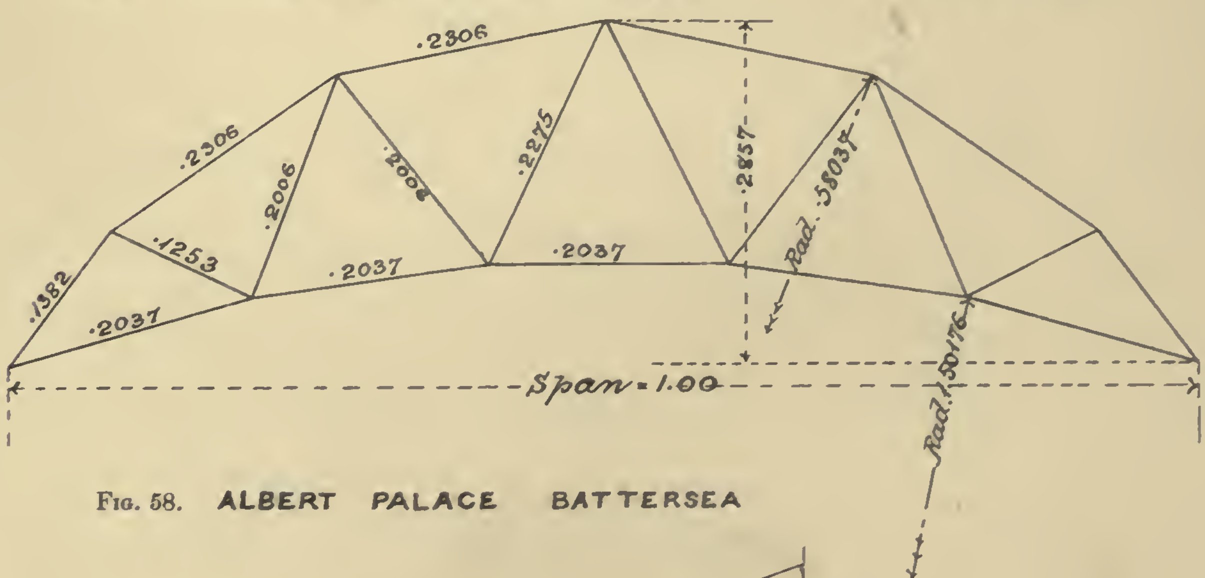


Fig. 58. ALBERT PALACE BATTERSEA

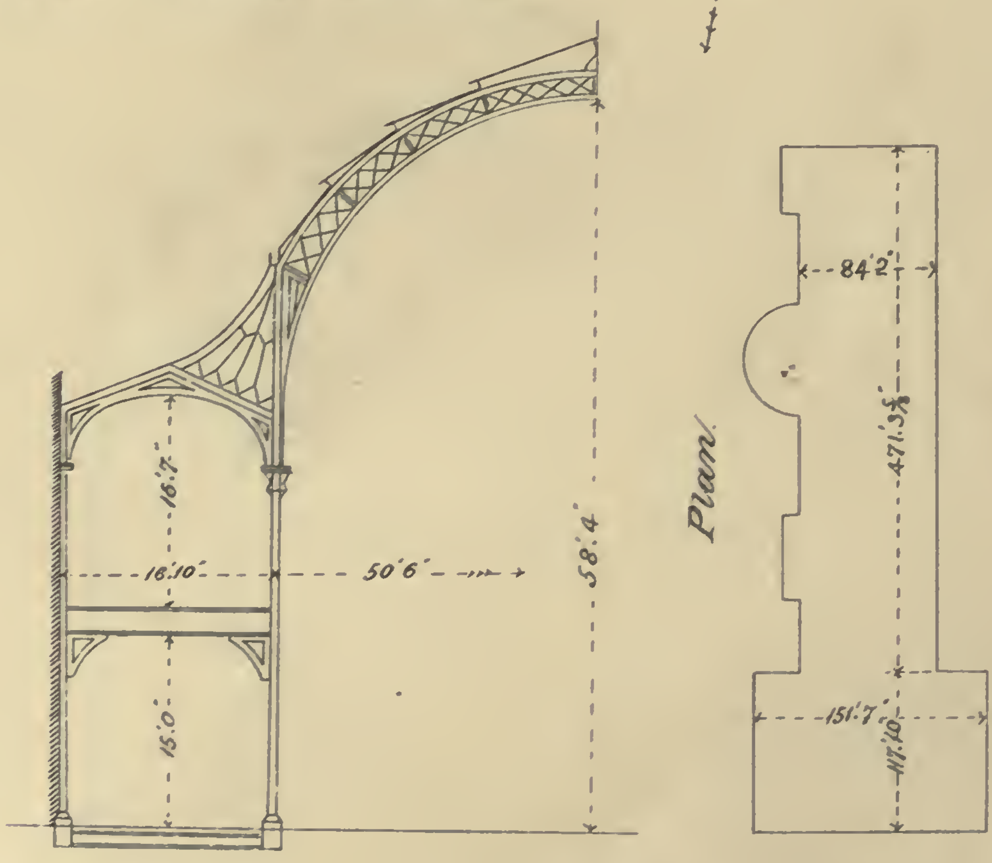
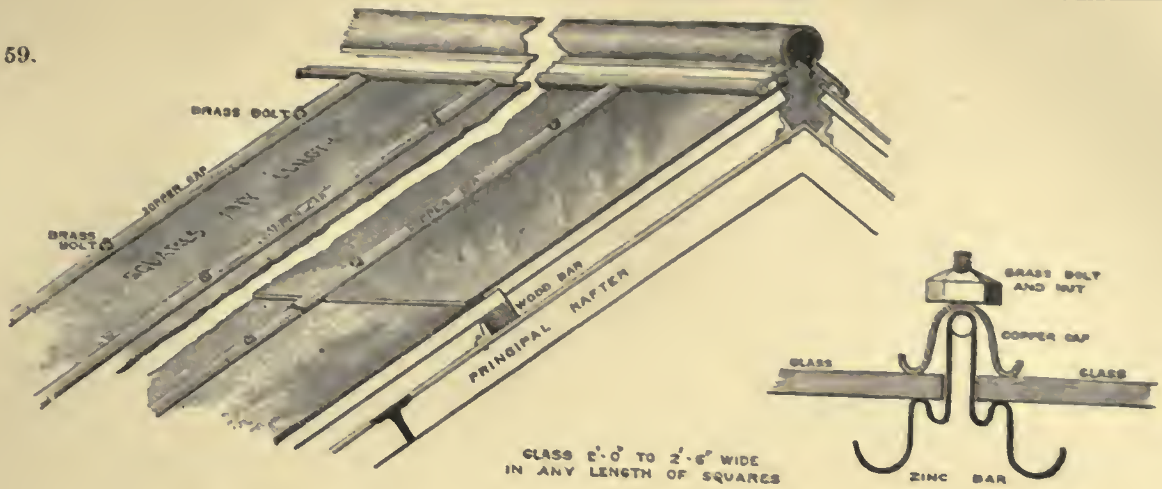
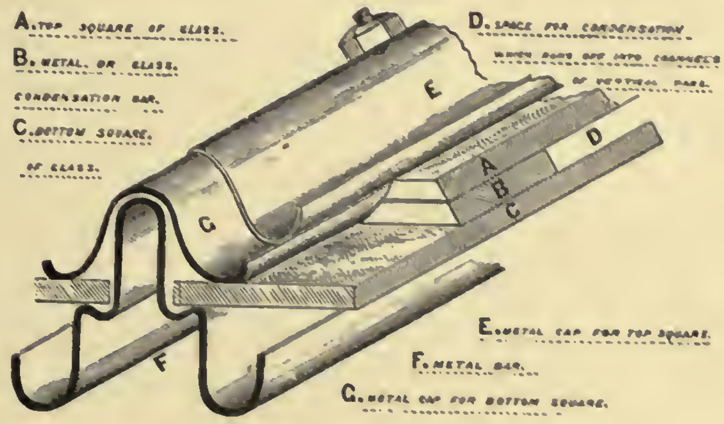


Fig. 59.



SECTION

Fig. 60.



NON-PUTTY SYSTEM OF GLAZING.

Fig. 61.

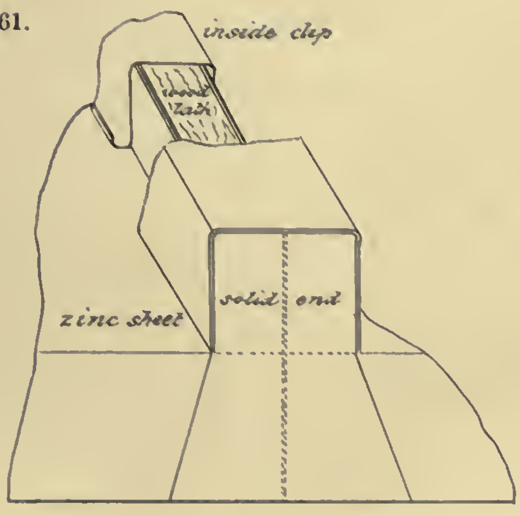
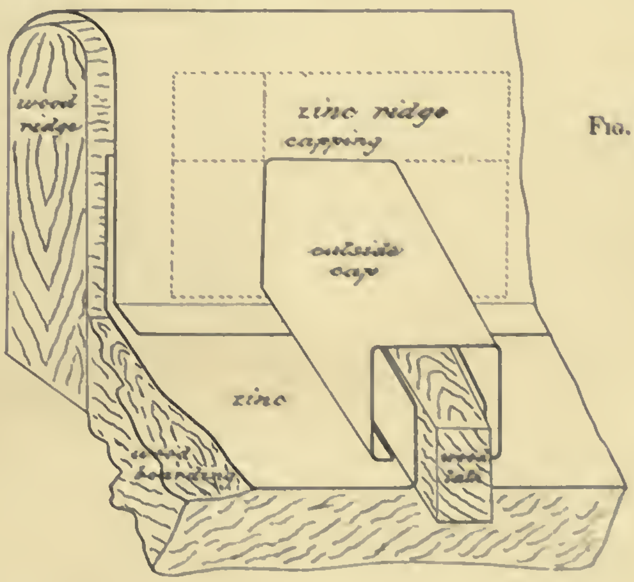


Fig. 62.



ZINC ROOFING WITHOUT EXTERNAL FASTENINGS OR SOLDER.

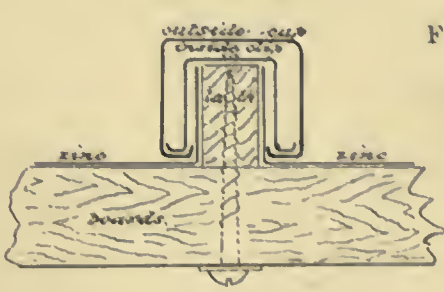
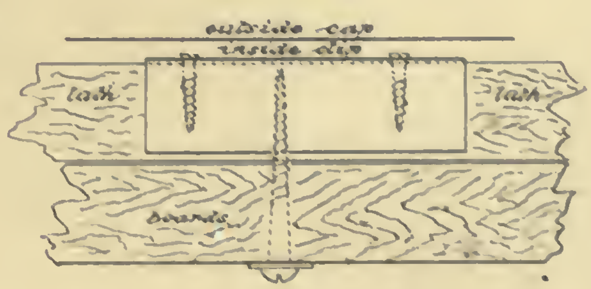
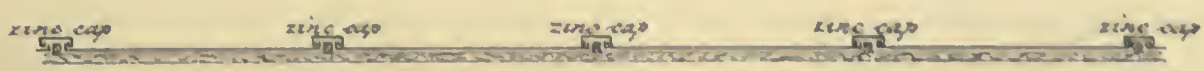


Fig. 63.





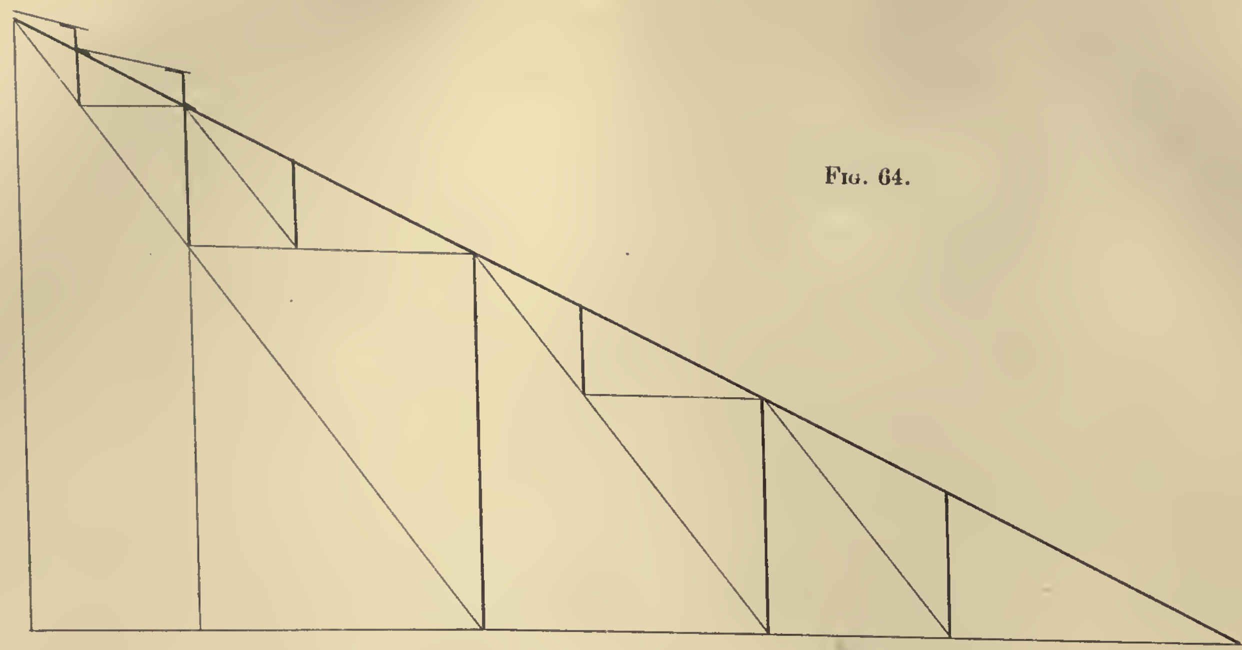
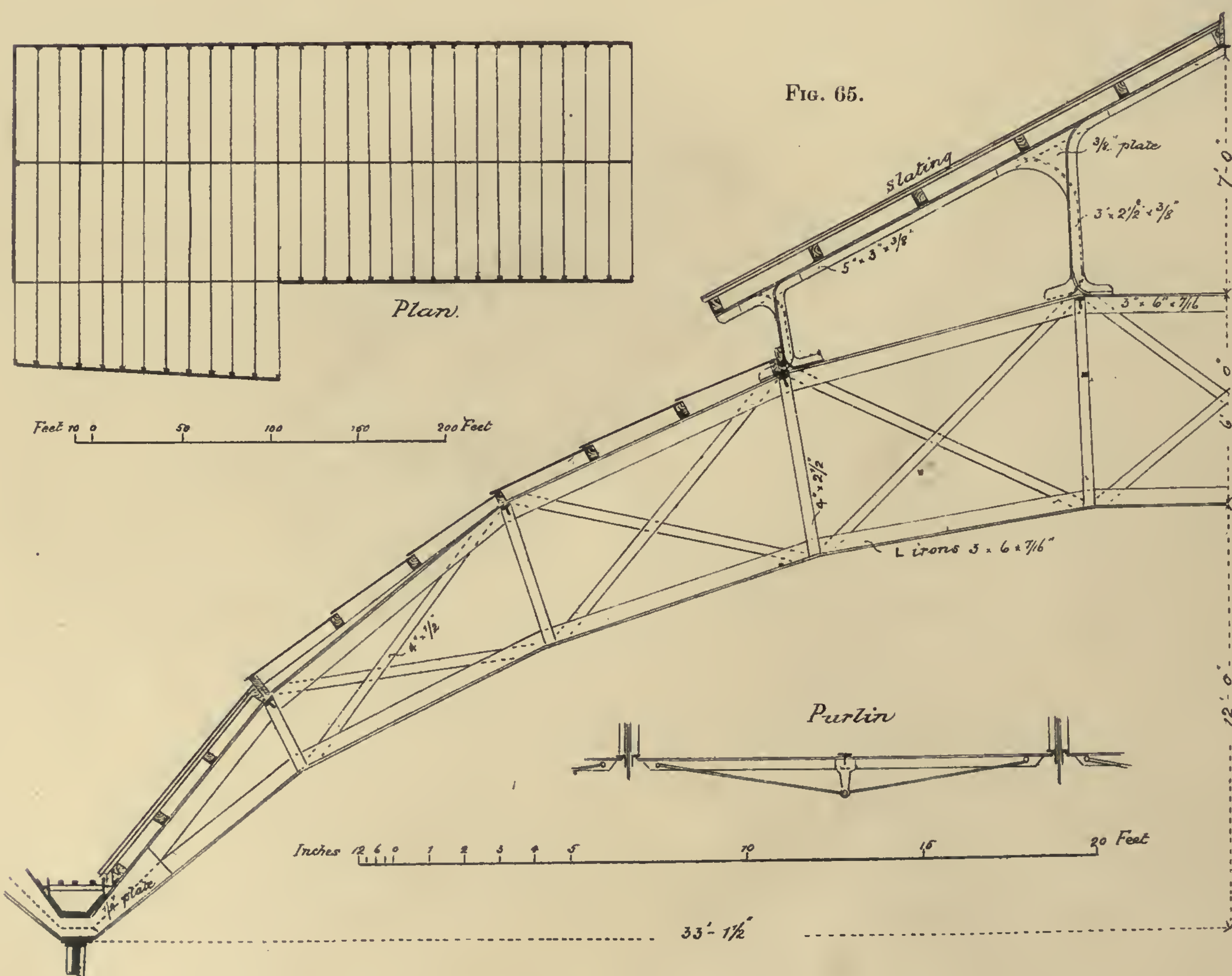


Fig. 64.

Fig. 65.


Plan
Feet 10 0 50 100 150 200 Feet
slating
Purlin
Inches 12 6 0 1 2 3 4 5 10 15 20 Feet
33'-1½"
L irons 3 x 6 x 7/16"

APPENDIX.

FIG. 1.

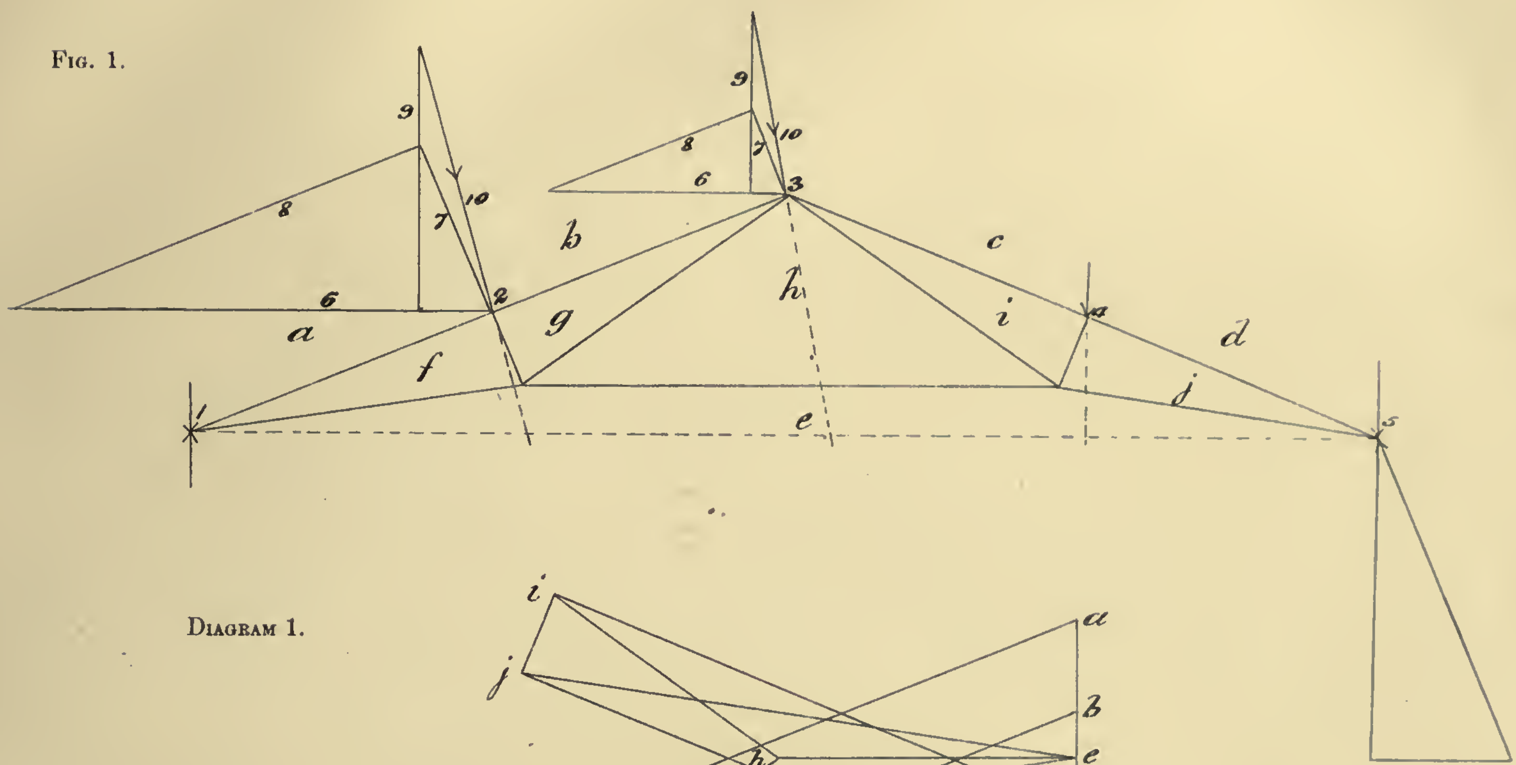


DIAGRAM 1.

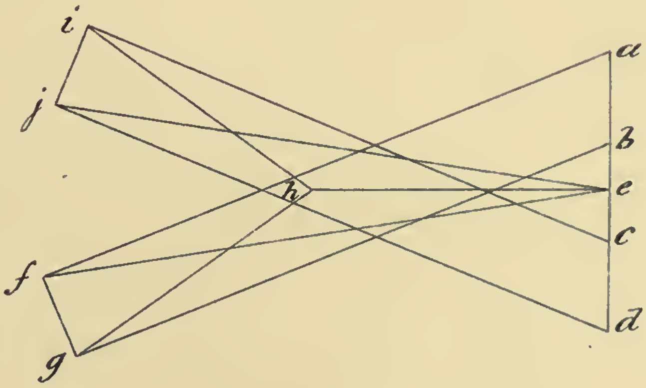
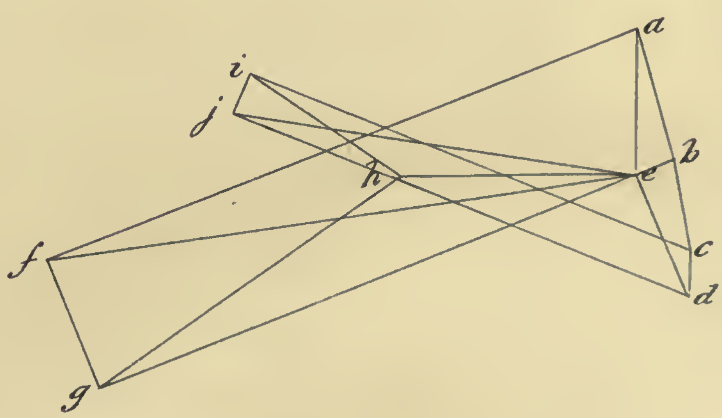


DIAGRAM 2.



For a comparison of Strains in Truss when (1) fixed upon the side exposed to the wind, and (2) fixed upon the lee-side, see page 17.

FIG. 2.

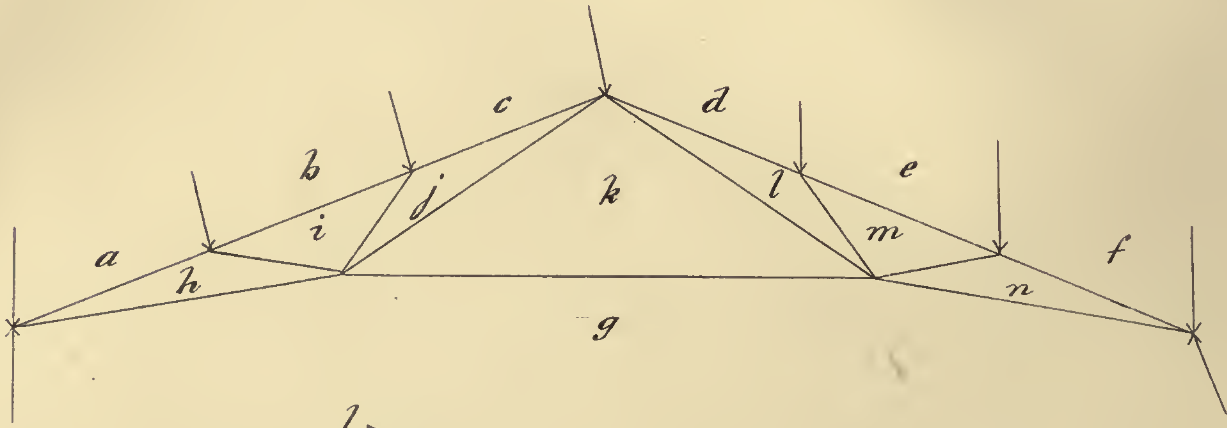


DIAGRAM 1.

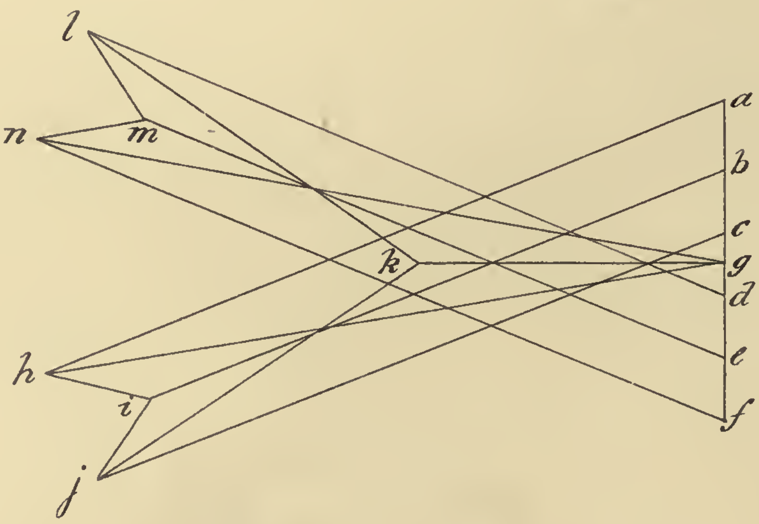


DIAGRAM 2.

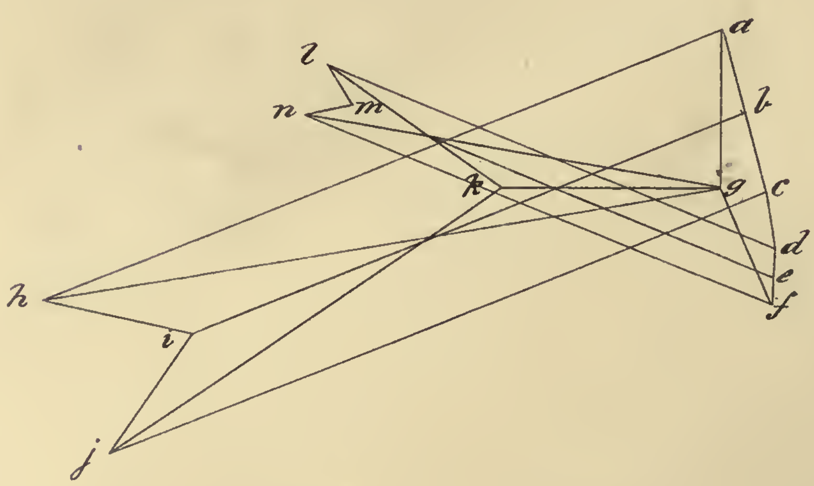


Fig. 8.

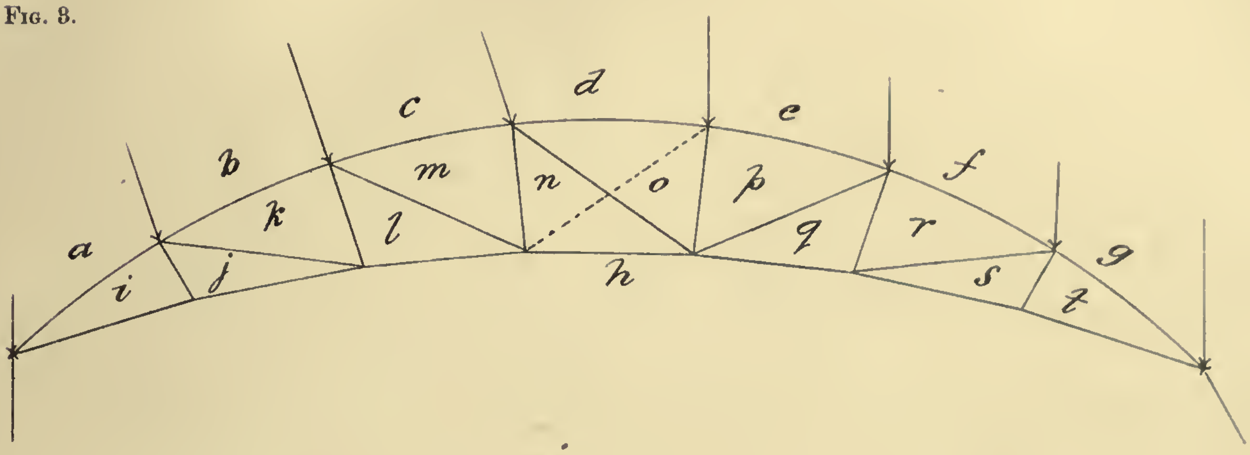
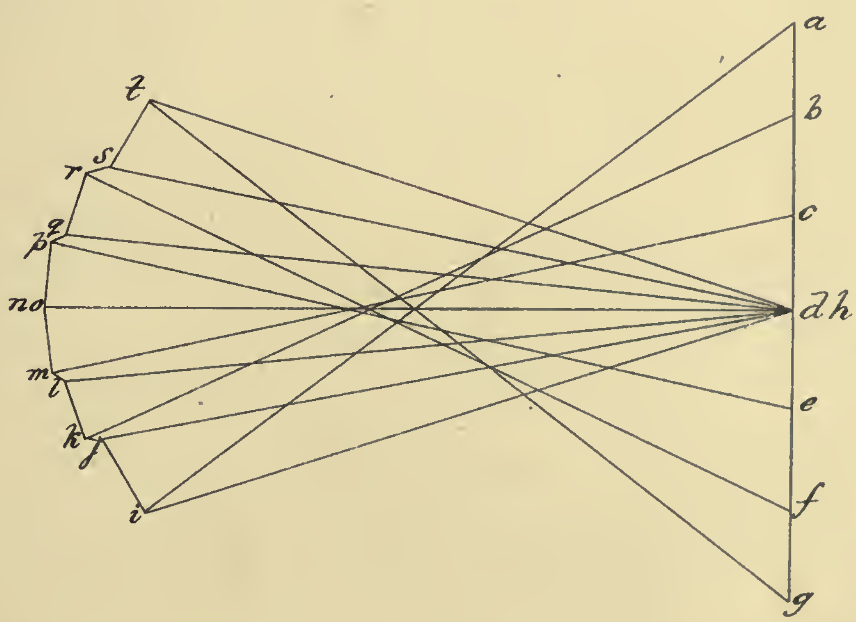


Diagram 1.



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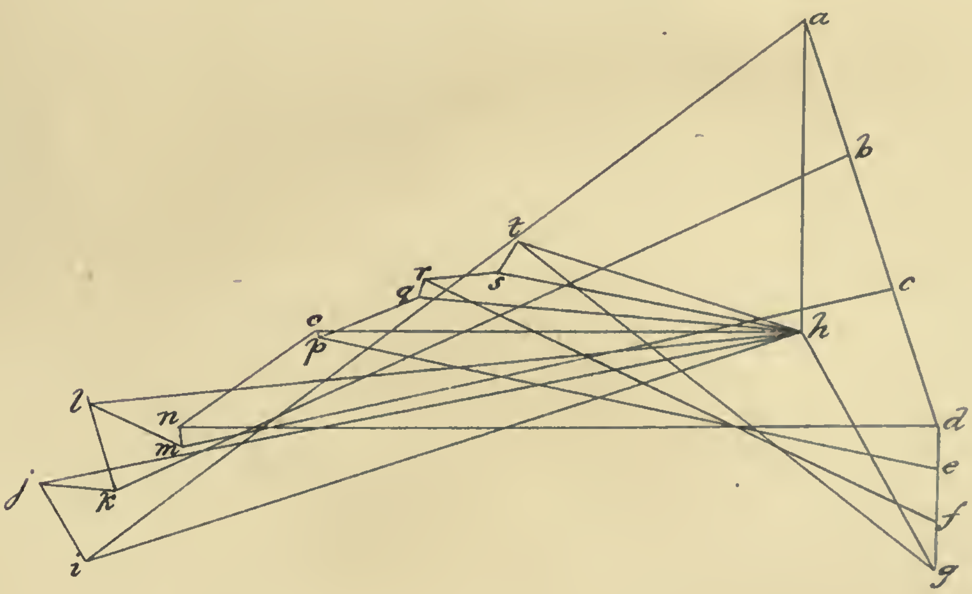


Figs. 4 and 5.

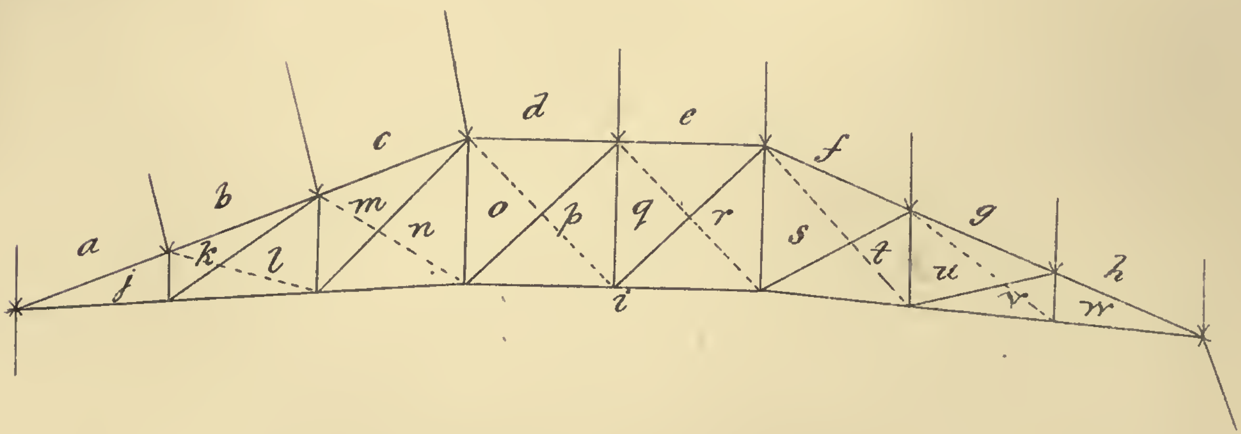


Diagram 1.

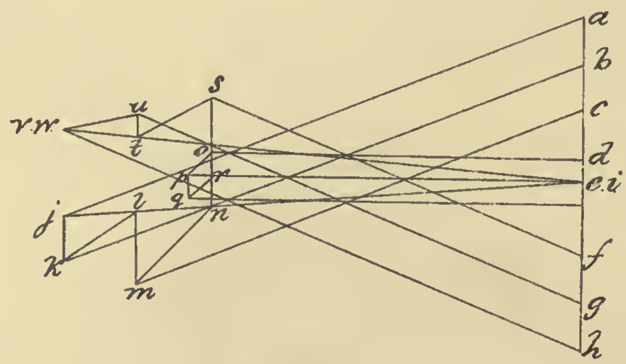


Diagram 2.

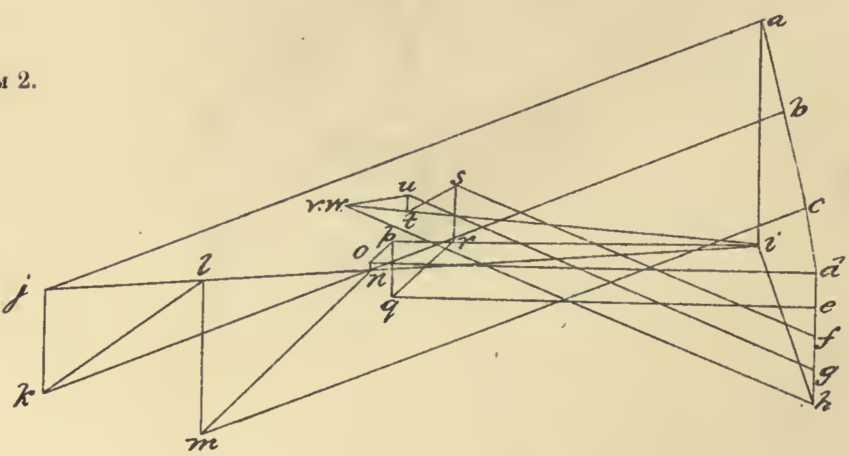


Fig. 6.

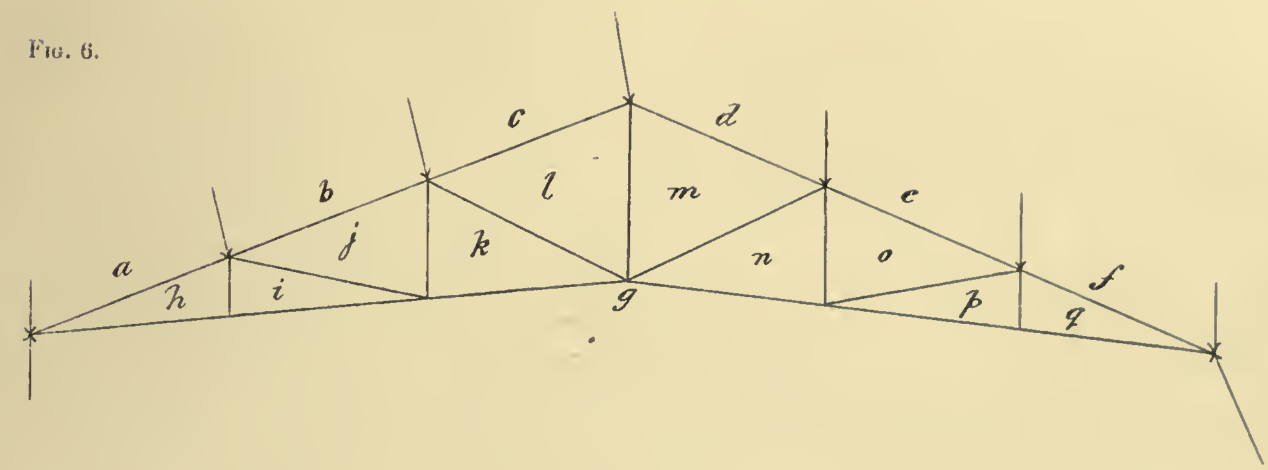


Diagram 1.

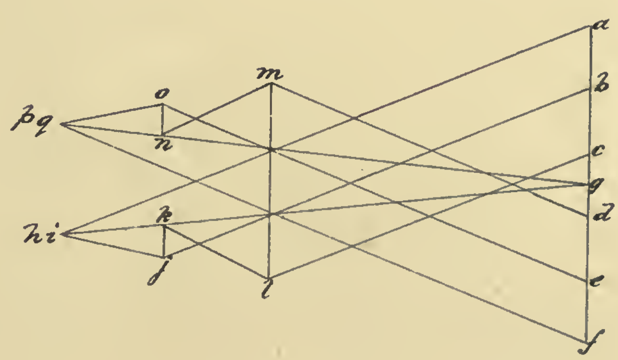


Diagram 2.

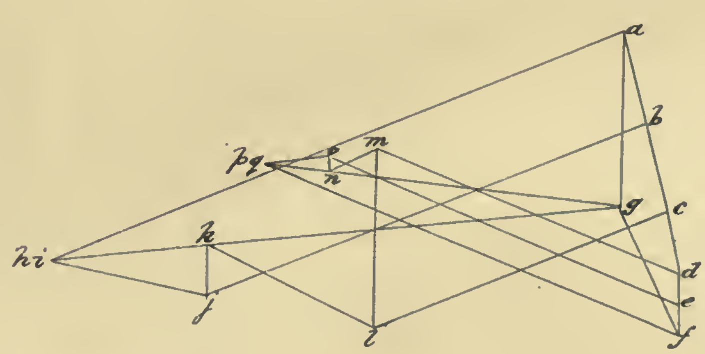


Fig. 7.

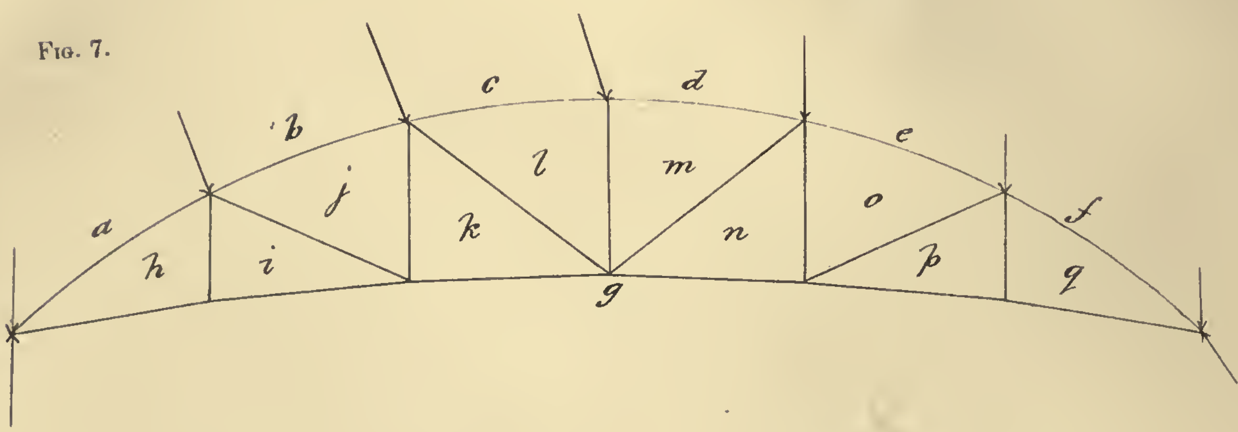


Diagram 1.

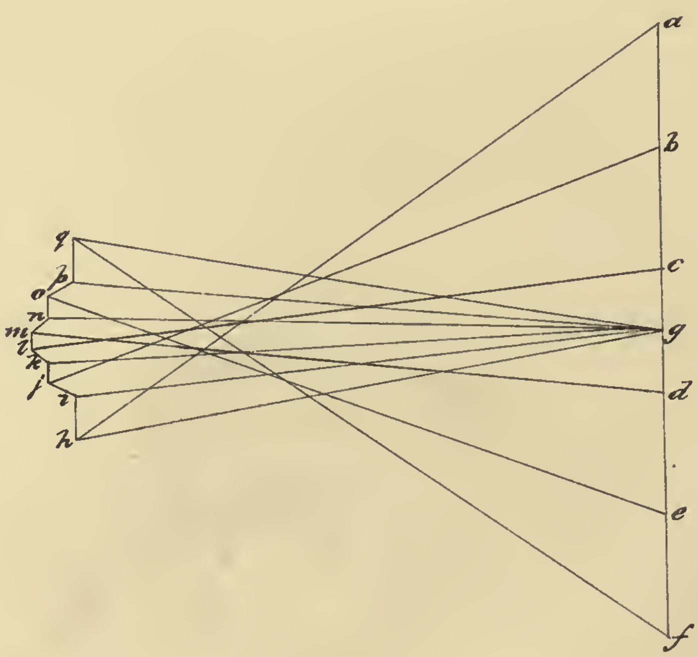


Diagram 2.

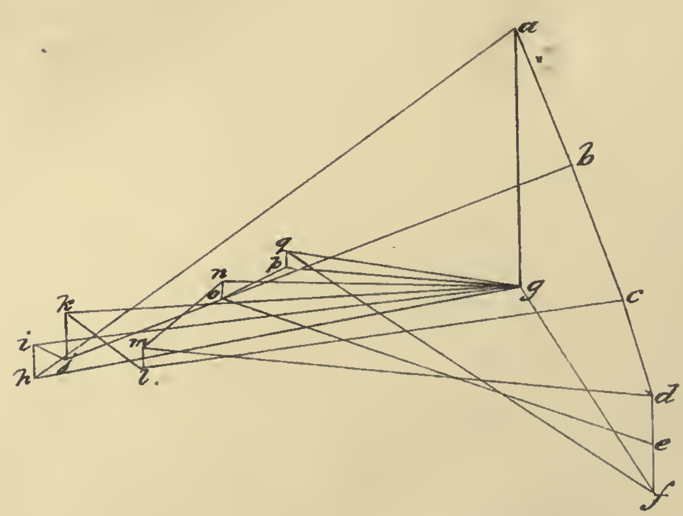


Fig. 8.

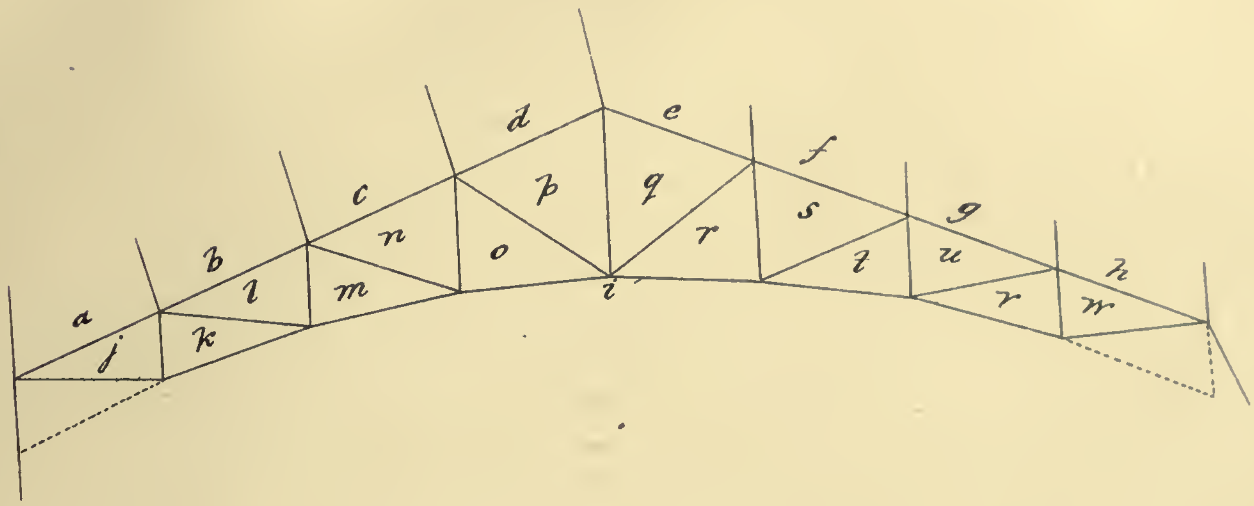


Diagram 1.

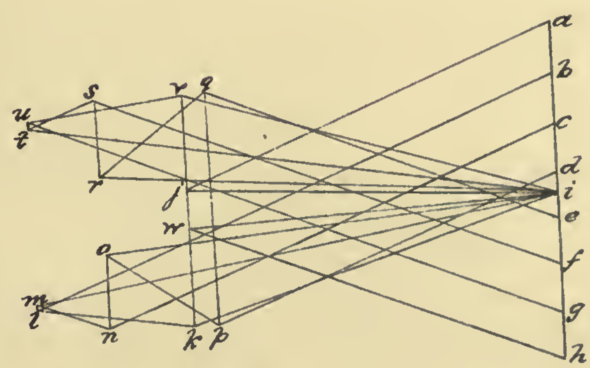


Diagram 2.

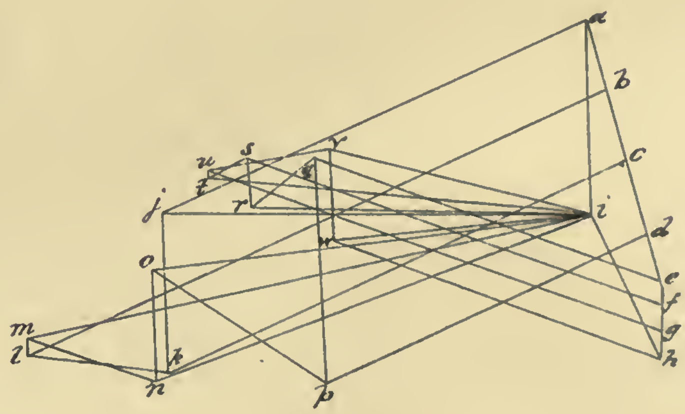


Fig. 9.

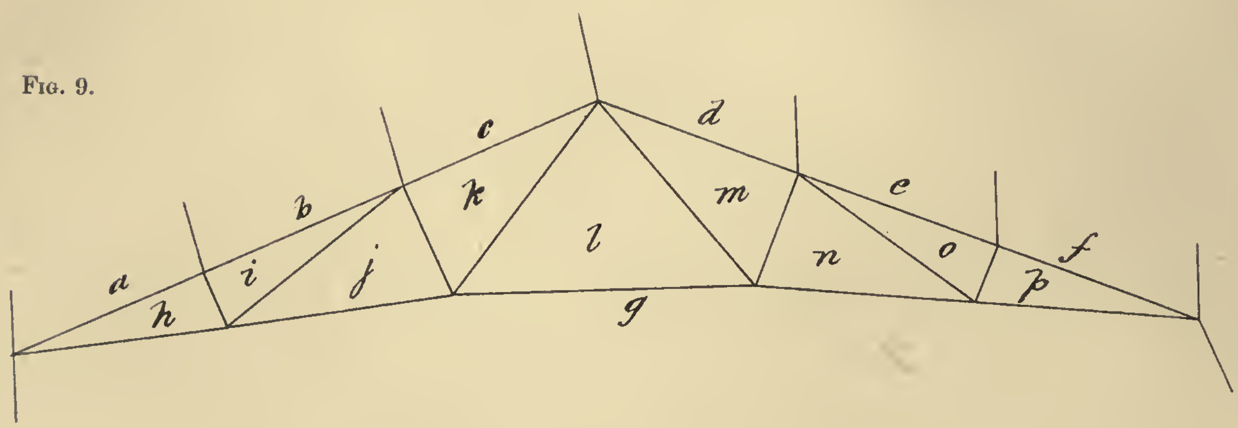


Diagram 1.

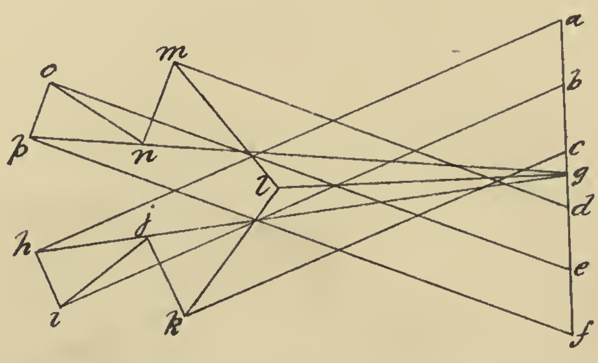


Diagram 2.

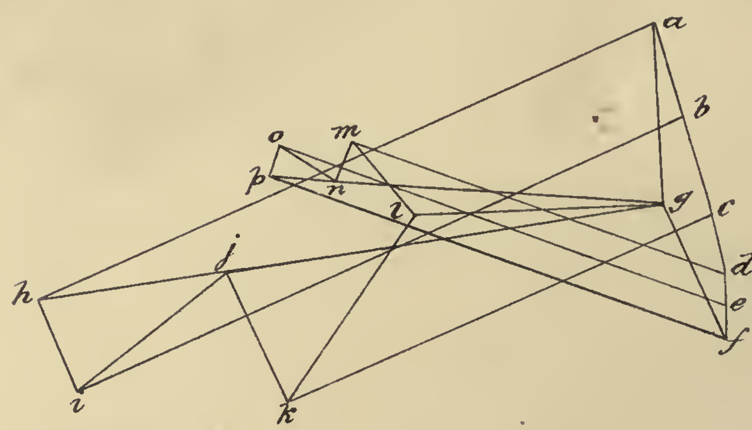


Fig. 10.

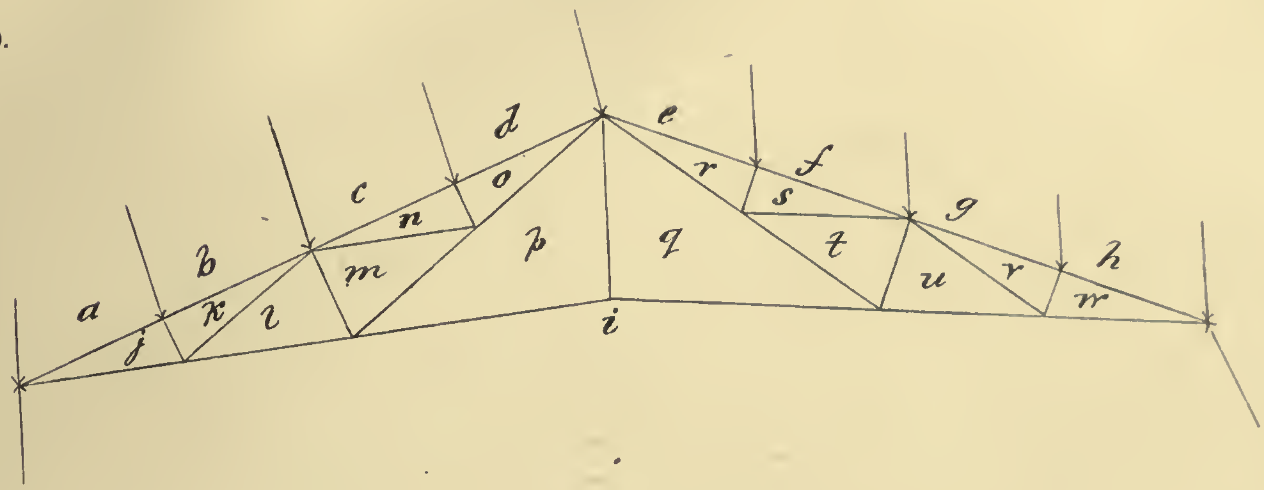


Diagram 1.

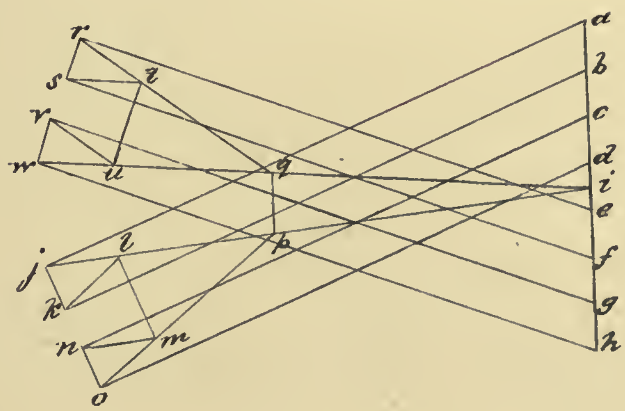


Diagram 2.

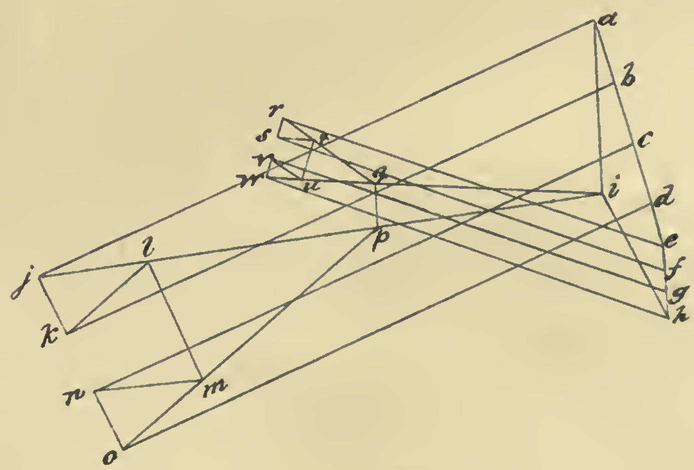


Fig. 11.

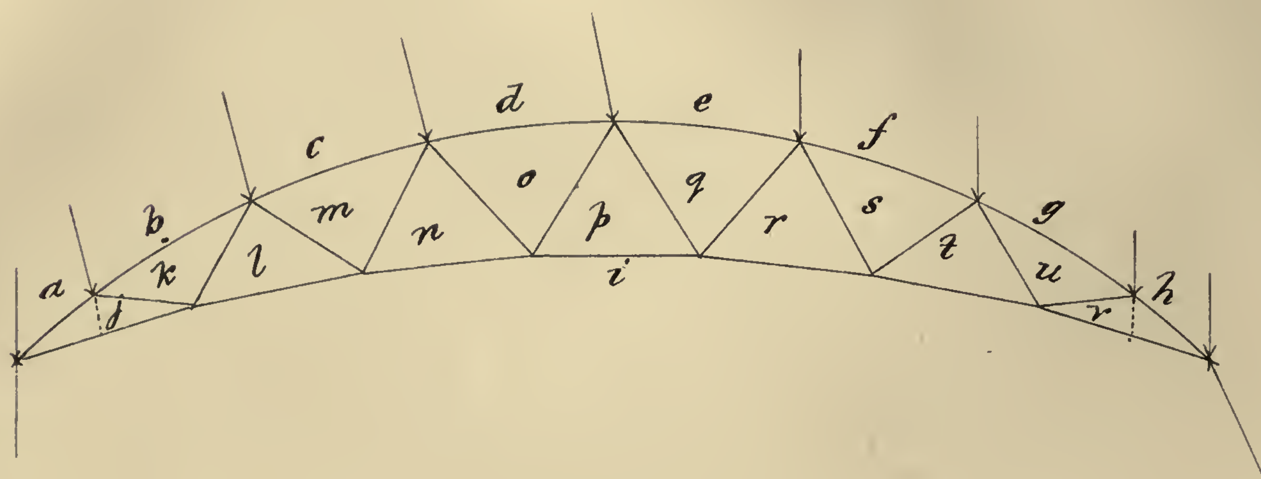


Diagram 1.

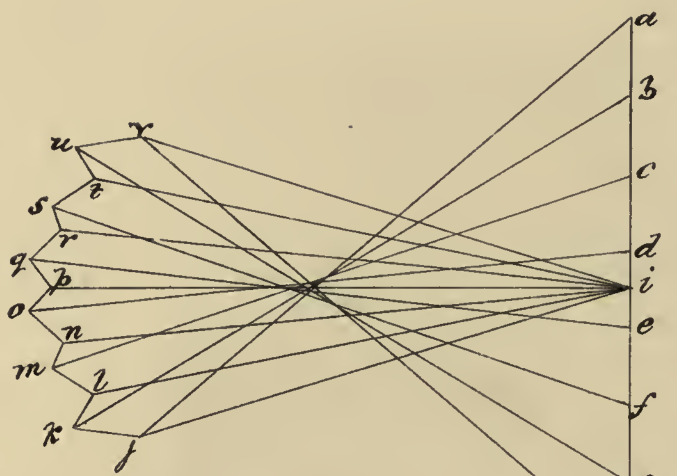


Diagram 2.

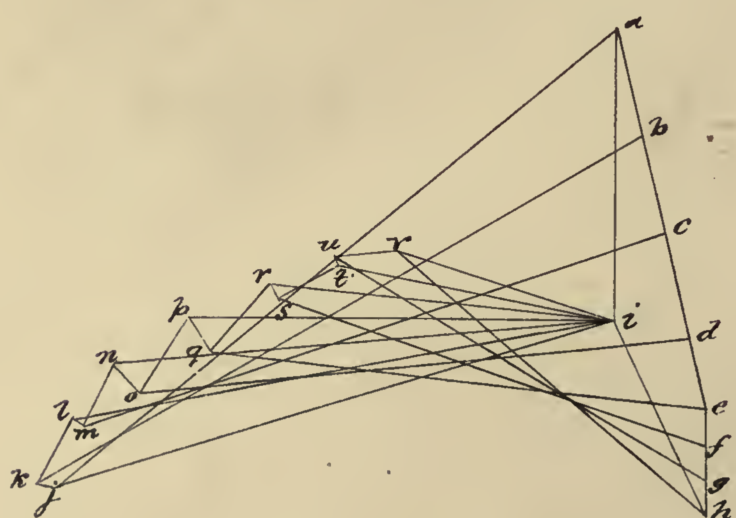


Fig. 12.

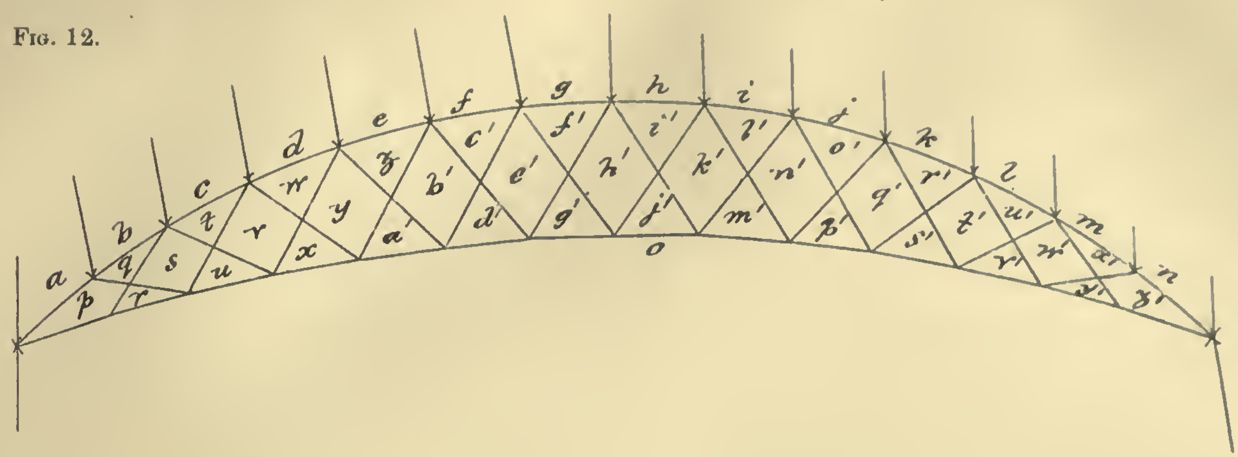


Diagram 1.

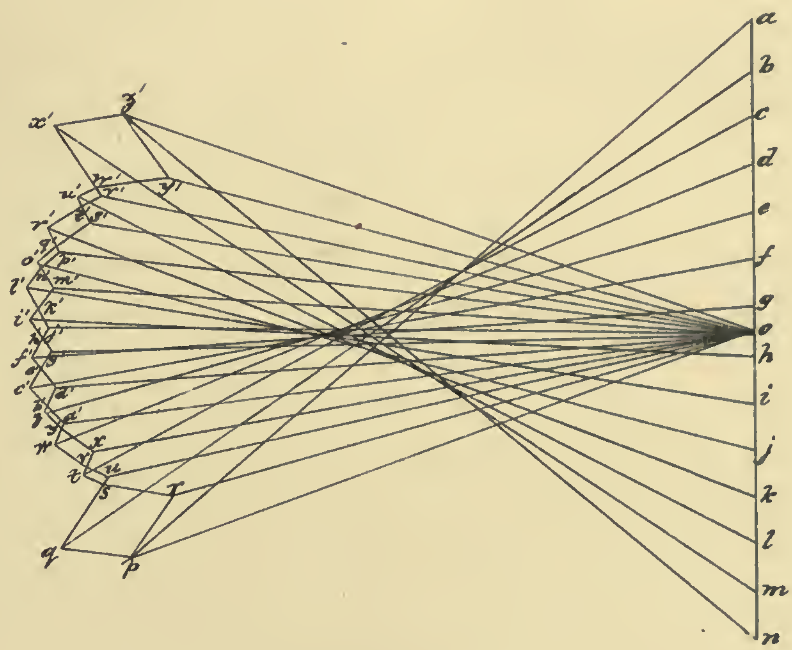
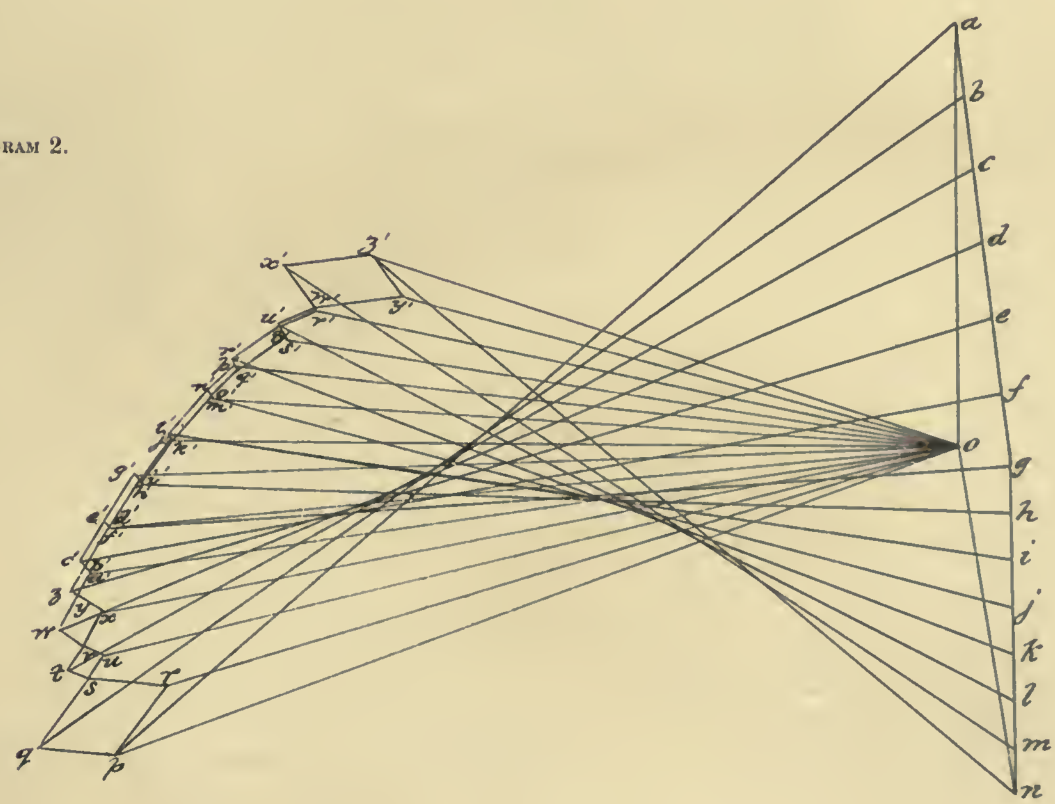
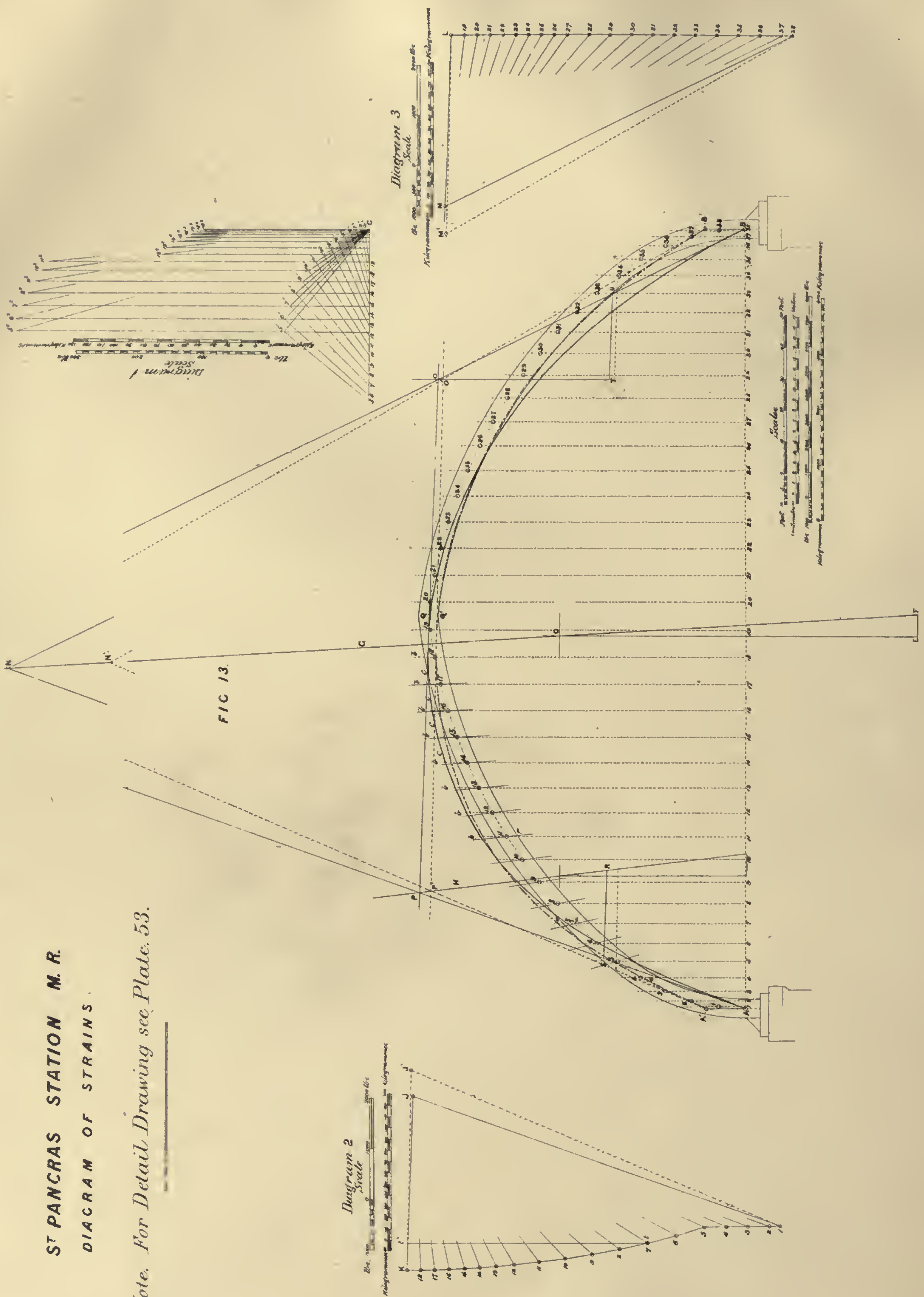


Diagram 2.





ST PANCRAS STATION M.R.

DIAGRAM OF STRAINS.

Note. For Detail Drawing see Plate. 53.

APPENDIX.

STRESSES IN ROOF PRINCIPALS.

Owing to the variation in the angles of the different members of roof principals (see Figures 1 to 12, pages 2 and 3) the calculation of the stresses by the use of formulæ is somewhat tedious, and the stresses have therefore been treated upon pages 41 to 51, *graphically*, as this appears to be the best and simplest method. It may be urged that mathematical accuracy by this means cannot be obtained, but *if the diagrams are drawn to a fairly large scale* these objections practically disappear, and the errors likely to occur in measuring the stresses arrived at by the graphic process, do not affect the result more than the errors which occur in the necessary measurement of angles when formulæ are employed. The graphic method has also two important advantages—first, that errors can be detected by a glance at the diagram; and secondly, that the character of stress in each member of the truss can easily be determined.

The types of trusses, Figures 1 to 12 (pages 2 and 3), are those usually adopted, and the following are the spans to which they may be best adapted. Figure 1 is the simplest form of roof principal, and is suitable for spans up to 40 feet; while Figure 2, which is somewhat similar in principle, may be used for spans from 30 feet to 60 feet. The remaining types (Figures 3 to 12) may be applied for almost any spans. For large spans some of the trusses would require a greater number of internal braces than is shown in Figures 3 to 12. This would not alter the type of the truss, but would give a larger number of bays, as it would be necessary to divide the rafter into lengths, small enough to prevent any buckling taking place.

The stress diagrams shown beneath the trusses, Figures 1 to 12, upon pages 41 to 51, *are drawn to various scales to suit the pages of this book*, and must therefore not be taken as representing *a comparison of the stresses* in the different types illustrated. The preliminary calculations are similar for all the types, and the explanation for Figure 1 (page 41) can be applied to any truss with which it is proposed to deal. In Figures 1 to 12 (pages 41 to 51) the first stress diagram is for vertical loads alone, while the second stress diagram includes both the vertical and horizontal loads.

The external forces acting on a roof are the constant weight of the structure itself, the variable weight of snow, acting vertically, and the pressure of the wind (which is usually taken as acting horizontally) upon one side only. The weight of roofing will vary with the covering, and also with the span and pitch of the principals. See Tables A to G, pages 78 to 80.

The wind pressure will vary with the locality. In some exposed situations it will be necessary to take a pressure of about 50 lb. to the square foot, but under ordinary circumstances a pressure of 40 lb. may be taken. The following Tables have been arrived at from formulæ based upon Hutton's experiments.*

P_n = Intensity of pressure normal to the surface.

P_v = „ vertical „

P_h = „ horizontal „

P = the assumed force of wind, 50 lb. per square foot in Table 1, and 40 lb. per square foot in Table 2, the pressure being taken upon a surface perpendicularly opposed to it.

i = the inclination to the wind's direction of any plane surface in a structure exposed to the wind.

$P_n = P \text{ sine } i^{\,(1 \cdot 84 \cos i - 1)}$.

$P_v = P \cos i \,.\, \text{sine } i^{\,(1 \cdot 84 \cos i - 1)}$.

$P_h = P \text{ sine } i^{\,(1 \cdot 84 \cos i)}$.

* *Vide* '*Iron Bridges and Roofs*' (*page* 120), *by Professor W. Cawthorne Unwin, B.Sc., F.R.S.*

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The wind force P is assumed to blow horizontally, and the resulting pressures upon the surfaces exposed at different angles are given under columns headed P_n, P_v, P_h.

TABLE No. 1. TABLE No. 2.

P = 50 lb. per square foot of surface.				P = 40 lb. per square foot of surface.			
Angle of Roof.	P_n	P_v	P_h	Angle of Roof.	P_n	P_v	P_h
5	6·3	6·1	0·5	5	5·0	4·9	0·4
10	12·1	12·0	2·1	10	9·7	9·6	1·7
20	22·6	21·3	7·8	20	18·1	17·0	6·2
30	33·0	28·5	16·5	30	26·4	22·8	13·2
40	41·6	31·9	26·8	40	33·3	25·5	21·4
50	47·6	30·6	36·5	50	38·1	24·5	29·2
60	50·0	25·0	42·5	60	40·0	20·0	34·0
70	51·3	17·5	48·1	70	41·0	14·0	38·5
80	50·5	8·8	49·8	80	40·4	7·0	39·8
90	50·0	0	50·0	90	40·0	0	40·0

The inaccuracy in the value of P_n for angles of 60°, 70°, and 80° is the result of the formula being only an approximate one. The results for angles intermediate in value between the above amounts can be easily calculated from the nearest values given in the above Tables.

Although in actual practice the rafters are made continuous, they are assumed in the calculation of strains to be hinged at the intersections, and the load is in each case assumed to be grouped together at the joints.

In Figure 1 each rafter of the principal is divided into two equal parts, therefore each part will sustain one-fourth of the total vertical load, which when grouped about the joints will give one-eighth at points 1 and 5, and one-fourth at each of the points 2, 3, and 4. The wind pressure, which is exaggerated so as to make a marked difference between the stress diagrams Nos. 1 and 2 for equal and unequal loading, is assumed to act upon the left side, and is grouped at joints 1, 2, and 3; therefore one-fourth will act at points 1 and 3, and one-half at point 2. Having obtained the distribution of the loads, we can proceed either (1) by resolving the horizontal forces into normal and tangential components, and then eliminating the tangential or non-effective portion, or (2) by estimating the normal components from the Table given above, which is deduced from Hutton's experiments. It will be found that the first of these methods furnishes the lowest result, so that the Tables err upon the side of safety. Further experiments must be made before a satisfactory conclusion can be drawn in favour of either method, and before a uniform system can be established.

It will readily be seen that the forces acting at points 1 and 5 will not enter into the calculation, as they are acting on the supports. Proceeding by the first of the above methods, the wind pressure is resolved into its normal and tangential components, and the tangential element eliminated before proceeding further. The horizontal lines 6, 6, which indicate the wind forces in magnitude and direction, are resolved into their normal and tangential components by drawing lines 7, 7 and 8, 8 respectively, at right angles as well as parallel to the back of the rafter, thus forming triangles of forces; the lines 8, 8 being the non-effective components. The forces represented in magnitude and direction by the lines 7, 7, together with the vertical loads acting at the joints, are the effective forces causing strains in the principal, and the resultant of these forces is arrived at by drawing lines 9, 9 vertically upwards from the extremities of 7, 7, then setting off the lengths with a scale of weights equal to the vertical loads, and drawing lines 10, 10 from their extremities to the joints where the loads act. Lines 10, 10 will then indicate in magnitude and direction the resultant of the forces acting at these joints. If the wind pressure is treated by the second method (see Table), lines 7, 7 must be drawn equal to the normal values of the wind pressure at the various angles between the part of the truss against which the wind is impinging and the horizontal; for example, the angle between the slope of the back of the truss at point 2 and the horizontal is 22°, and taking an initial pressure of 40 lb. per superficial foot, the unit of the effective normal pressure to be taken will be 19·8 lb. per superficial foot measured upon the sloping surface. The reaction of the supports at the

springing points of the roof must now be determined, and their magnitude and direction must be such, that they will exactly equilibrate the effective forces previously arrived at. To obtain the reactions of the supports, lines 10, 10 and the vertical lines indicating the forces at points 4 and 5 must be produced, until they cut a horizontal line drawn between the points of support, and the vertical lines 9, 9 produced downwards, until they cut the horizontal lines indicating the pressure of the wind, which will give the vertical and horizontal components of the resultants at points 2 and 3. The vertical reaction of the right support will now equal the sum of the vertical forces, multiplied by their distances from the left support, and divided by the span. The reaction of the left support will equal the sum of the vertical forces, multiplied by their distances from the right support and divided by the span. It will be well to make both these calculations to assure accuracy, as their sums should equal the sum of the vertical forces, although it is only necessary to calculate one of them, the other being found by subtracting the reaction so found, from the sum of the vertical forces. The horizontal reaction can be assumed to act at either the right or left support, depending upon which side relative to the prevailing winds the truss is fixed. Fixing it upon the same side as the wind is acting, will give the maximum stresses, and at the side opposed to the wind the minimum ; the side on which the horizontal reaction is assumed to act will of course be the side upon which the roof is fixed, the expansion rollers or free end of the truss being opposite to it. This is a point that must be well considered before calculation, because a roof exposed to the wind on both sides would be subject to its maximum or minimum stresses according as the wind was blowing on the free or fixed side, and in some light high-pitched roofs there would be a danger of the tie-rod being put in compression and the roof buckling up, if the wind were blowing upon the free side, should there be no means provided to prevent it. Upon a roof consisting of two or more spans, the outward slopes of the roof only would be subject to wind pressure, so that if the internal feet of the principal were fixed, and there were no fear of the roof buckling, the roof would be subject only to the minimum strains, and the maximum if the external feet were fixed. In all the diagrams (pages 41 to 51) the principals are assumed to be fixed upon the side opposed to the wind. On vertical lines drawn downwards from the points 1 and 5 are set off the vertical reactions of the supports, and from the point thus obtained on the right-hand side, a horizontal line is drawn equal to the sum of the horizontal forces acting upon the principal, then the line drawn from its extremity to point 5 will indicate the reaction of the right support in magnitude and direction, while the reaction of the left support is indicated by the vertical line already set off. If these calculations have been made correctly, the resultants of the forces acting on the roof, and the two reactions, when drawn in a force diagram, *will form a complete polygon.*

The stress diagrams 1 and 2 are drawn by a method emanating from Professor Clerk Maxwell, and the notation or system of lettering the parts is that advocated by Mr. R. H. Bow in his 'Economics of Construction,' which is as follows :—In the diagram of the truss a letter is written in each space, and the letters which indicate spaces in the truss indicate points in the diagram, so that each line in the truss is indicated by letters on each side, and the corresponding lines in the stress diagrams are represented by the same letters at each end. The spaces outside the truss between the forces are also lettered and become points in the stress diagram. To letter the parts, commence with the first letter of the alphabet, in the space between the reaction and the force at point 2, and insert the letters B, C, D between the remaining forces, and E between the two reactions and the tie-rod, then letter all the spaces in order, F to J respectively, beginning with the first space on the left-hand side. The different parts of the rafter F A, G B, I C, and J D, of F E the tie-rod, of H E and J E, and F G, G H, H I, and I J in the bracing, will, when the stress diagram is drawn, have their letters at each end of the line. From any point A, diagram 2, draw A B *to scale* parallel and equal to the resultant indicated by line 10, acting at point 2. A different scale to that adopted for Figure 1 may be used for this, if found convenient. From point B thus obtained draw B C equal to line 10 acting at point 3, and from C, line C D acting at 4, and from point D, draw D E parallel and equal to the reaction at the right support; then from E a line drawn parallel and equal to the reaction at the left support will, if the previous calculations have been made correctly, exactly join up at the point A, and form the polygon of the external forces. In drawing the polygon, care must of course be taken to draw the lines in the direction in which the forces are acting. From

points A and B draw lines parallel to A F and B G, and from points C and D draw lines parallel to C I and D J. Then the points where lines drawn from E parallel to E F and E J cut the lines drawn from A and D will be points F and J, and will also determine the amount of the stresses in the four lines A F, D J, F E, and J E. Then lines drawn from F and J parallel to F G and I J until they cut lines drawn from B and C will fix points I and G, and lines drawn from E, G, and I parallel to E H, G H, and I H will, if the diagram is drawn correctly, join up in the point H. The lines measured off with the scale to which the diagram is drawn, will give the stresses in the members indicated by the letters.

The character of the stresses in the rafters will be in compression and of the tie-rod in tension. Provided the system of lettering recommended above has been adopted, the character of the stresses in the bracing will be in tension, if the direction indicated by the letters is acting upwards towards the truss or in compression if acting downwards; for example, the member indicated by F G in the diagram of the principal, reads downwards, that is to say, G being the following letter in the alphabet is below F in the stress diagram, it will therefore be a strut, and as the member G H reads upwards, H being above G, it will therefore be a tie. If the calculations are made, as in this case, with the horizontal reaction opposite to the wind, when—owing to the pitch of the roof and the lightness of the structure, compared with the pressure of the wind—there is a tendency for the roof to collapse by the buckling of the tie-rod, it would be apparent that the stress in the tie-rod would be a compressive one, which would be indicated in the stress diagram by the lines indicating the stress in the tie-rod being drawn in the opposite direction to which they are shown.

With the preceding explanation no difficulty will be found with Figures 1, 2, 6, 7, and 9. In trusses where there is a redundance of parts, it will be necessary to make some modification before drawing a stress diagram, that is to say, where more than two parts of the bracing join up in one point, there will either be one strut and two ties, or two struts and one tie to deal with, which will make it impossible to state definitely what proportion of the stress the members in duplicate are subject to. It will therefore be necessary to disregard the superfluous members by treating them separately. Figure 3, page 43, shows a form of truss in which there are two superfluous members when the truss is acted upon by an uniformly distributed load only, viz. the two diagonal braces in the centre of the span. When acted upon by a load that is not uniformly distributed, such as the dead load and wind pressure combined, there would be one superfluous member, viz. that shown by a dotted line. In drawing stress diagram 1 for the dead load, the two superfluous members will be left out, and letters N, O will indicate one point only in the stress diagram. In stress diagram 2, in which the wind pressure is also taken into account, the dotted member only will be left out; but if the wind were assumed to be acting on the right-hand side, it will be seen that the member indicated by the dotted line will be required, and its corresponding diagonal would become useless, so that both are really required in construction, but only one will act at one time. Hence they will both require to be proportioned to the same stress. Figures 4 and 5, page 44, where there is a greater number of superfluous parts, are treated upon the same principle, the dotted lines indicating the members which do not act when the wind is acting upon the left side. These as before will all come into use when the wind is acting upon the right side; thus, in Figures 4 and 5 the strain in the dotted diagonals situated in the left-hand bays of the truss, when the wind is acting on the left-hand side, will be the same as the strains in the diagonals shown by full lines *q r*, *s t*, *u v* respectively. Figure 8, page 47, is a truss in which the dotted members at the springing points are not required for the stress diagram, but in which the vertical dotted members sustain a compressive force equal to the reactions. Figure 10, page 49, is a type which requires another calculation to be made before the stresses can be arrived at by a diagram, the stresses in the part of the tie-rod P I must be previously ascertained. This is best done by taking moments round the apex, that is to say, the stress in the tie-rod multiplied by the distance of the tie-rod (measured at right angles) from the apex plus the sum of the oblique forces (which indicate the resultants of the vertical load and the wind pressure as indicated by lines 10 in Figure 1) multiplied by their distance (measured at right angles) from the apex, equals in amount the reaction of the left support multiplied by its distance (measured at right angles) from the apex. When this stress has been ascertained, it should be plotted in the stress

diagram on the line drawn from point I parallel to the part of the tie-rod P I which will determine P, and enable the remainder of the diagram to be drawn. Figure 11, page 50, presents no difficulty, but attention is called to it on account of the two dotted members near the supports which do not appear in the stress diagram, as they form no part of the bracing of the structure, but are simply introduced as a preventative against the sagging of the tie-rod. Figure 12, page 51, although drawn precisely as Figure 11, has a double system of bracing, but as two members only meet in any one point there is no redundance of parts.

ST. PANCRAS PASSENGER STATION ROOF (M. R.).

Description of Diagram of Strains (Figure 13, Page 52).

The following particulars of the above roof (see Plates 53 to 56) are taken from Mr. W. H. Barlow's paper, vol. xxx., p. 78, 'Minutes of Proceedings of the Institution of Civil Engineers.' Clear span, 240 feet. Clear rise, 96 feet. Distance apart of ribs, 29 feet 4 inches. Depth of rib, 6 feet. The strains are worked upon a method described by Mr. William Bell, M. Inst. C.E., in his paper entitled 'The Stresses of Rigid Arches' ('Minutes Proceedings Inst. C.E.,' vol. xxxiii.).

In the diagram the rib has been divided into 38 parts, measuring 8·7 feet along the neutral line, the centre of each part being indicated upon the diagram by small circles.

The investigation of stresses has been made for a length of 1 foot of the roof longitudinally, so that the results have been multiplied by 29 feet 4 inches (the distance apart of the ribs) to obtain the stresses in each rib. The loads acting on the roof have been assumed as

Weight of rib (lattice portion), 11 lb. per foot super.
„ „ Covering slated, 36 „ „ „
„ „ „ glazed, 18 „ „ „

Vertical loads, { 222 lb. at points 1 and 38.
420 „ from points 2 to 11, and 28 to 37.
252 „ „ „ 12 to 27.

The loads acting at points 1 and 38 are those due to the weight of the rib only, which is heavier at the springing. A wind pressure of 40 lb. per super. foot has been assumed to act upon one side of the roof only, between points 5 and the crown, the side wall protecting the roof from wind below point 5.

The total wind forces acting at the divisions of the rib have been resolved into normal and tangential components, the total horizontal forces from which the normal and effective forces are derived being given in Table I., page 60. The construction of the load diagram is as follows:—From any point C, Diagram 1, are drawn C 5, C 6, &c., equal to the horizontal forces acting at points 5, 6, &c., in the curve, through point C, lines C 5′, C 6′, &c., are drawn normal to the curve at points 5, 6, &c., and lines 5 5′, 6 6′, &c., are drawn from the points 5, 6, &c., perpendicular to the normal lines to which they correspond; thus a series of triangles of forces is formed corresponding to the different points in the arch, and the normal or effective forces are scaled off and tabulated. We have now for effective forces from points 5 to 19 the normal values of the wind force and the vertical loads. These forces are again each formed into a triangle of forces to find the oblique resultants; this is effected by simply drawing vertical lines $5^1\ 5^2$, $6^1\ 6^2$, &c., equal to the vertical forces (for amounts, see Table II., page 60) and connecting points 5^2, 6^2, &c., with the point C, lines 5^2 C, 6^2 C, &c. The resultants of the forces in magnitude and direction are then indicated. Vertical ordinates are drawn from the springing line through the points in the neutral line, and from points 5 to 19 oblique lines are also drawn through these points parallel to the resultants, found in Diagram 1. The vertical lines $5^1\ 5^2$, $6^1\ 6^2$, &c., in the load diagram are produced to the horizontal line C 5, Diagram 1; so that the distances measured vertically from the horizontal line to 5^2, 6^2, &c., measure the vertical components of the total effective forces and horizontal lines measured from the

points where the verticals cut the horizontal line to point C are the horizontal components. We have now obtained definite values for the loading, and can easily find the resultant of all the loads by taking moments with the vertical and horizontal components. Table II. gives the value of the vertical forces, the horizontal distances (or leverages) from point A (the springing point round which moments have been taken), and the moments, which are the products of the vertical forces and the leverages. The sum of the moments divided by the sum of the vertical loads gives the horizontal distance of the resultant of the vertical forces from A which is 117·015 feet (see page 60). Table III. gives the effective horizontal forces (page 61), the vertical distances or leverages from the springing line, and the moments. The vertical distance of the resultant of the horizontal forces from the springing line is the sum of the moments divided by the sum of the horizontal forces which is 58·024 feet (see page 61). The vertical height and the horizontal distance so obtained are plotted on the diagram, and point (D) where they intersect will be the point through which the resultant will pass. The vertical line D E is drawn from point D equal to the total vertical load 13,971 lb. given in Table II., and from the point E so obtained the horizontal line E F is drawn to scale equal to the total horizontal force 851·5 given in Table III. (page 61), and the resultant G is arrived at by drawing a line through points D and F, the length D F measuring its magnitude. The resultants H and I of all the forces on the left and right halves of the rib are found in exactly the same way as the resultant of the whole of the forces, and the values from which they are obtained are given in Tables IV., V., VI., and VII. (pages 61 and 62).

As a preliminary process, the curve of equilibrium for a rigid arch hinged at the crown and springing was drawn, the curve therefore had to pass through the crown and springing, thus fixing three points in the curve.

The direction of the thrusts at the crown and springing were obtained by drawing lines N A, N B tentatively until the point N was so fixed that a line connecting the points of intersection P and O (where lines N A and N B cut H and I) passed through the point Q at the crown of the arch. In the illustration the lines N A and N B are shown broken, to save space. The triangles of force giving the amounts of the stresses in the three lines A P, P O, and O B are drawn by plotting from P and O respectively, the previously obtained values of the forces acting in the lines of the resultants H and I, and from R and T so obtained S R and T U are drawn parallel to P O cutting P A and O B produced in S and U, therefore the lines S P, S R or T U and U O measure the stresses required. Lines K J (Diagram 2) and M L (Diagram 3) are drawn parallel to P O and scale lengths equal to S R or T U, and lines K 18, 18–17, 17–16, &c., on the left side (Diagram 2), and L 19, 19–20, 20–21, &c., on the right side (Diagram 3) are drawn equal and parallel to the resultants of the effective forces acting through the points which the numbers indicate. If the diagram is drawn correctly, lines 1 J and 38 M will scale equal to S P and O U respectively, and a line connecting points K and 1 will be equal and parallel to P R, and the total length L 38 will scale equal to O T. The curve of equilibrium on the left side is constructed by drawing between the lines *b, b, b* representing the force resultant, lines *c, c, c* parallel to 18 J, 19 J, &c., from Diagram 2. The curve on the right side is constructed in a similar manner, only using Diagram 3 instead of Diagram 2 for the elements of the curve. If the curve is drawn correctly it will be found exactly to cut points A and B.

As the St. Pancras roof is rigid at the crown and springing (the shoes of the ribs being securely fixed to massive foundations), the curve of equilibrium had to satisfy the following conditions :—

$$\Sigma\left(\frac{P\,N}{I}\right) = O \text{ and } \Sigma\left(\frac{P\,N}{I} \times p\,q\right) = O;$$

where Σ = sum, and $P\,N = M$ = bending moment at each point in the curve,

I = moments of inertia at each section,

$p\,q$ = ordinates measured from the points in the curve of neutral line to the springing line.

These formulæ were first applied to the curve which passed through the crown and springing point, but the conditions were not satisfied, so that trial curves had to be drawn until the true one was found by altering the height of the curve at the crown and shifting the springing points. In

drawing the trial curves it is easily seen from the summation whether the crown or springing of the curve requires altering. The curve satisfying the equations passes very near the lower flange of the rib at the crown, and the springing points are shifted vertically upwards to points A′ and B′. The points in the diagrams referring to the correct curve satisfying the required conditions are indicated by the same letters as the first curve, with the addition of a distinguishing mark, for example, point A in the first curve is marked A′ in the second. In drawing the second curve, points K 18, &c., to I and L 19, &c., to 38 indicating the loads were of course the same as before, and lines K J′ and L M′ were drawn parallel to the new line of thrust P′ O′, at the crown from points K and L. To satisfy the first equation, the sum of the vertical ordinates between the curve of equilibrium and the neutral line divided by I where the curve of equilibrium is above the neutral line, must equal the sum of the ordinates divided by I where it is below. To satisfy the second equation, the sum of the same ordinates above and below must equal each other when they are multiplied by the corresponding ordinates measured from the springing line to the neutral line. For ordinates between the neutral line and curve of equilibrium from points 5 to 19, a correction had to be made because the lines of force were not vertical, vertical lines were therefore drawn on the force diagram through the points 18, 17, 16, &c., to cut the line K J, and any point as t, was treated as if it formed part of a diagram where lines K 18, 18–17, 17–16, &c., were vertical, and the thrust therefore J t' instead of J K; the lengths of the vertical ordinates $u\,v$, $u\,w$, corresponding to that point and representing M, were multiplied by the ratio $\frac{J\,t'}{J\,K}$ before being put in the summation; and a similar corresponding ratio was used for the other points, as for point 7, where the forces were not vertical. It will be evident that the greatest bending moment occurs where the curve of equilibrium is furthest from the neutral line; in this case point 11 on the left side, and 33 on the right side will therefore be subject to the greatest bending moments. Referring to the strain diagrams 2 and 3, it will be found that the direct stresses measure 4750 lb. and 6280 lb. respectively. Taking moments for the force acting at 11 round r, the neutral axis of the inner flange $S\,P = S'q \therefore S = \frac{S'q}{P}$,

where S = total stress in the outer flange,
S′ = direct stress measured on diagram,
P = distance apart of neutral axes of flanges,
q = distance of curve of equilibrium from point r.

Substituting the values in the above equation, we have total stress in outer flange = $\frac{4750 \times 9 \cdot 4}{6} = 7442$ lb. This being the stress for one longitudinal foot of roof, and the distance apart of the ribs being 29 feet 4 inches, the maximum stress in the outer flanges of the rib will be 7442 lb. × 29 feet 4 inches = 218,299 lb. = 97·5 tons. The actual section of each flange being 23 square inches, the stress per square inch will be $\frac{97 \cdot 5}{23} = 4 \cdot 24$ tons. The moment of stress to be overcome in fixing the rib at the springing will be that resulting from the horizontal thrust acting at the assumed springing points A′ and B′. The maximum horizontal thrust occurs at the springing B′, which is 52 tons; this multiplied by the leverage B B′ will give the moment to be resisted in fixing the rib at its base.

In making these calculations the moment of inertia has been taken at the same value throughout, except at points 1 and 38, where it was assumed to be double that of the other points. In Table VIII., page 63, the first and third, and second and fourth totals should be equal; it will be seen that the first and third are practically equal, but that there is a difference of 1½ per cent. between the second and fourth totals. Greater accuracy might have been attained by again shifting the curve. The diagram from which these calculations were made was drawn to about four times the size of that indicated upon page 52. It was found that the curve would only require shifting about ¼ of an inch; this would be of very little practical importance, and with the use of so small a scale would not be apparent.

TABLE I.

Pressure of Wind.

Point.	Vertical area.	Pressure per foot sup.	Total pressure.	Effective pressure scaled from diagram, page 52.
	feet.	lb.	lb.	lb.
5	6·80	40	272	164·4
6	6·60	"	264	143·6
7	6·20	"	248	122·6
8	5·80	"	232	100·2
9	5·40	"	216	83·6
10	5·00	"	200	65·6
11	4·65	"	186	52·0
12	4·25	"	170	40·2
13	3·85	"	154	29·4
14	3·45	"	138	20·4
15	3·00	"	120	13·2
16	2·60	"	104	8·5
17	2·20	"	88	5·0
18	1·80	"	72	2·2
19	1·40	"	56	0·6
	63·00	Total effective pressure		851·5 lb.

TABLE II.

Moments of Vertical Components of Wind Force and Vertical Loads.

Point.	Vertical force.	Horizontal distance from A.	Moment.
	lb.	feet.	
1	222	0·6	133·2
2	420	2·3	966·0
3	420	5·4	2268·0
4	420	9·7	4074·0
5	554	14·8	8199·2
6	554	20·3	11246·2
7	546	26·5	14469·0
8	536	32·9	17634·4
9	526	39·4	20724·4
10	516	46·6	24045·6
11	504	53·8	27115·2
12	326	61·3	19983·8
13	314	69·3	21760·2
14	303	77·1	23361·3
15	291	85·3	24822·3
16	282	93·6	26395·2
17	273	101·9	27818·7
18	266	110·5	29393·0
19	260	119·0	30940·0
20	252	127·9	32230·8
21	252	136·3	34347·6
22	252	144·8	36489·6
23	252	153·1	38581·2
24	252	161·5	40698·0
25	252	169·7	42764·4
26	252	177·5	44730·0
27	252	185·1	46645·2
28	420	192·6	80892·0
29	420	199·7	83874·0
30	420	206·9	86898·0
31	420	213·5	89670·0
32	420	219·6	92232·0
33	420	225·7	94794·0
34	420	231·4	97188·0
35	420	236·5	99330·0
36	420	240·8	101136·0
37	420	243·9	102438·0
38	222	245·6	54523·2
	13,971 lb.		1634811·7

$$\left.\begin{array}{r}\text{Horizontal distance of resultant}\\ \text{of vertical forces from point A}\end{array}\right\} = \frac{1634811\cdot 7}{13971} = 117\cdot 015 \text{ feet.}$$

TABLE III.

Moments of Horizontal Components of Wind Forces.

Point.	Horizontal Force.	Vertical distance from Springing.	Moment.
	lb.	feet.	
5	164·4	39·80	6543·12
6	143·6	46·40	6663·04
7	122·6	52·56	6443·86
8	100·2	58·52	5863·70
9	83·6	64·16	5363·78
10	65·6	69·48	4557·89
11	52·0	74·40	3868·80
12	40·2	79·20	3183·84
13	29·4	82·96	2439·02
14	20·4	86·52	1765·01
15	13·2	89·68	1183·77
16	8·5	92·42	785·57
17	5·0	94·92	474·60
18	2·2	96·80	212·96
19	0·6	98·20	58·92
	851·5		49407·88

Vertical distance of resultant of horizontal forces from springing line $= \frac{49407 \cdot 88}{851 \cdot 5} = 58 \cdot 024$ feet.

TABLE IV.

Moments of Vertical Components of Wind Force and Vertical Loads in Left Half of Arch about Point A.

Point.	Vertical Force.	Horizontal distance from A.	Moment.
	lb.	feet.	
1	222	0·6	133·2
2	420	2·3	966·0
3	420	5·4	2268·0
4	420	9·7	4074·0
5	554	14·8	8199·2
6	554	20·3	11246·2
7	546	26·5	14469·0
8	536	32·9	17634·4
9	526	39·4	20724·4
10	516	46·6	24045·6
11	504	53·8	27115·2
12	326	61·3	19983·8
13	314	69·3	21760·2
14	303	77·1	23361·3
15	291	85·3	24822·3
16	282	93·6	26395·2
17	273	101·9	27818·7
18	266	110·5	29393·0
	7273		304409·7

Horizontal distance of resultant of forces on left half of arch from point A .. $= \frac{304409 \cdot 7}{7273} = 41 \cdot 85.$

TABLE V.

Moments of Horizontal Components of Forces on Left Half of Arch about Point A.

Point.	Horizontal Force.	Vertical distance from Springing.	Moments.
	lb.	feet.	
5	164·4	39·80	6543·12
6	143·6	46·40	6663·04
7	122·6	52·56	6443·84
8	100·2	58·52	5863·70
9	83·6	64·16	5363·78
10	65·6	69·48	4557·89
11	52·0	74·40	3868·80
12	40·2	79·20	3183·84
13	29·4	82·96	2439·02
14	20·4	86·52	1765·01
15	13·2	89·68	1183·77
16	8·5	92·42	785·57
17	5·0	94·92	474·60
18	2·2	96·80	212·96
	850·9		49348·94

Vertical height above springing of resultant of horizontal forces on left half of arch above point A .. .. $\left.\right\} = \frac{49348 \cdot 94}{850 \cdot 9} = 58$ feet.

TABLE VI.

Moments of Vertical Component of Wind Force and Vertical Load at Point 19, and Moments of Vertical Forces from Point 20 to 38 in Right Half of Arch about Point A.

Point.	Vertical Forces.	Horizontal distances from A.	Moments.
	lb.	feet.	
19	260	119·0	30940·0
20	252	127·9	32230·8
21	252	136·3	34347·6
22	252	144·8	36489·6
23	252	153·1	38581·2
24	252	161·5	40698·0
25	252	169·7	42764·4
26	252	177·5	44730·0
27	252	185·1	46645·2
28	420	192·6	80892·0
29	420	199·7	83874·0
30	420	206·9	86898·0
31	420	213·5	89670·0
32	420	219·6	92232·0
33	420	255·7	94794·0
34	420	231·4	97188·0
35	420	236·5	99330·0
36	420	240·8	101136·0
37	420	243·9	102438·0
38	222	245·6	54523·2
	6698		1330402·0

Horizontal distance of resultant of vertical forces on right half of arch from point A $\left.\right\} = \frac{1330402}{6698} = 198 \cdot 6$ feet.

TABLE VII.

Moment of Horizontal Component of Force 19 on Right Half of Arch about Point A.

Point.	Horizontal Force.	Vertical distance from Springing.	Moment.
19	0·6	98·20	58·92

TABLE VIII.

Curve above Neutral Line.				Curve below Neutral Line.			
Point.	$\frac{PN}{I}$.	PQ.	$\frac{PN}{I} \times PQ$.	Point.	$\frac{PN}{I}$.	PQ.	$\frac{PN}{I} \times PQ$.
1	2·40	8·60	20·64	3	1·40	25·00	35·00
2	0·40	16·80	6·72	4	0·60	32·80	19·68
5	1·08	39·80	42·98	18	0·48	96·92	46·52
6	3·00	46·12	138·36	19	2·00	98·40	196·80
7	4·60	52·60	241·96	20	2·80	98·40	275·52
8	5·68	58·60	332·84	21	2·72	96·92	263·62
9	6·60	64·20	423·72	22	2·72	95·00	258·40
10	6·72	69·60	467·71	23	2·72	92·60	251·87
11	6·90	74·40	517·82	24	2·92	89·80	262·22
12	6·48	78·88	511·14	25	2·92	86·60	252·87
13	5·76	82·92	477·61	26	2·88	82·92	238·81
14	4·92	86·52	425·67	27	3·12	78·88	246·11
15	3·72	89·76	333·90	28	3·00	74·20	222·60
16	2·52	92·48	233·05	29	3·12	69·40	216·53
17	1·12	94·88	106·26	30	3·60	64·12	230·83
38	2·60	8·40	21·84	31	4·12	58·60	241·43
	64·560		4302·22	32	4·60	52·52	241·59
	$\Sigma\left(\frac{PN}{I}\right)$		$\Sigma\left(\frac{PN}{I} \times PQ\right)$	33	5·08	46·20	234·70
				34	5·40	39·48	213·19
				35	5·52	32·68	180·39
				36	4·00	25·00	100·00
				37	0·40	16·80	6·72
					66·12		4235·40
					$\Sigma\left(\frac{PN}{I}\right)$		$\Sigma\left(\frac{PN}{I} \times PQ\right)$

DESCRIPTION OF THE PLATES.

In the Plates illustrating this work every detail is accompanied with a scale expressed both in English and French measures, and the principal dimensions are figured in feet and inches upon the details. As the illustrations are reduced by photography, it will be found that the actual length of the divisions upon the scales does not generally correspond with the manufactured sizes of scales, but the details possess the following advantage, namely, that, as they are photographed direct from large scale drawings, the smaller parts, when examined with the aid of a magnifying glass, stand out clear and plain.

The type of truss shown in Figure 1 (page 1) has been adopted in the roof over the Kingsbridge Station, Dublin (Great Southern and Western Railway of Ireland), which consists of five spans, each 32 feet 6 inches with principals placed 7 feet 3 inches (centres) apart. The Blythwoodholme Arcade, Glasgow (Figure 15, page 5), connects Waterloo Street with Bothwell Street, and has a side entrance to Hope Street. There are ten ribs, about 12 feet 6 inches apart, forming nine central bays, in addition to two hipped ends. The ironwork was made by Messrs. Handyside and Co. Plates 1 to 4 illustrate the Bristol Junction Station (Great Western Railway and Midland Railway), described upon page 5 (Figure 14). The ironwork was made by the late firm of Messrs. Vernon and Ewens, Cheltenham.

The form of truss shown in Figure 2 (page 2) is liable to prove defective in lateral stiffness, as it does not admit of a convenient method of tying the principals together horizontally. The roof covering the Portadown Station of the Great Northern Railway of Ireland has two spans with this form of truss, the horizontal tie being held up in the centre by a sling rod suspended from the apex of each principal. The spans are 45 feet 9 inches and 58 feet 9 inches respectively.

In the roof over the Midland Railway Station at Derby, the principals are connected below the top flange of the transverse girders (see Figure 66), and the type of truss adopted is that shown in Figure 6. One argument in favour of placing as much of the ironwork in a railway roof outside as

Fig. 66.

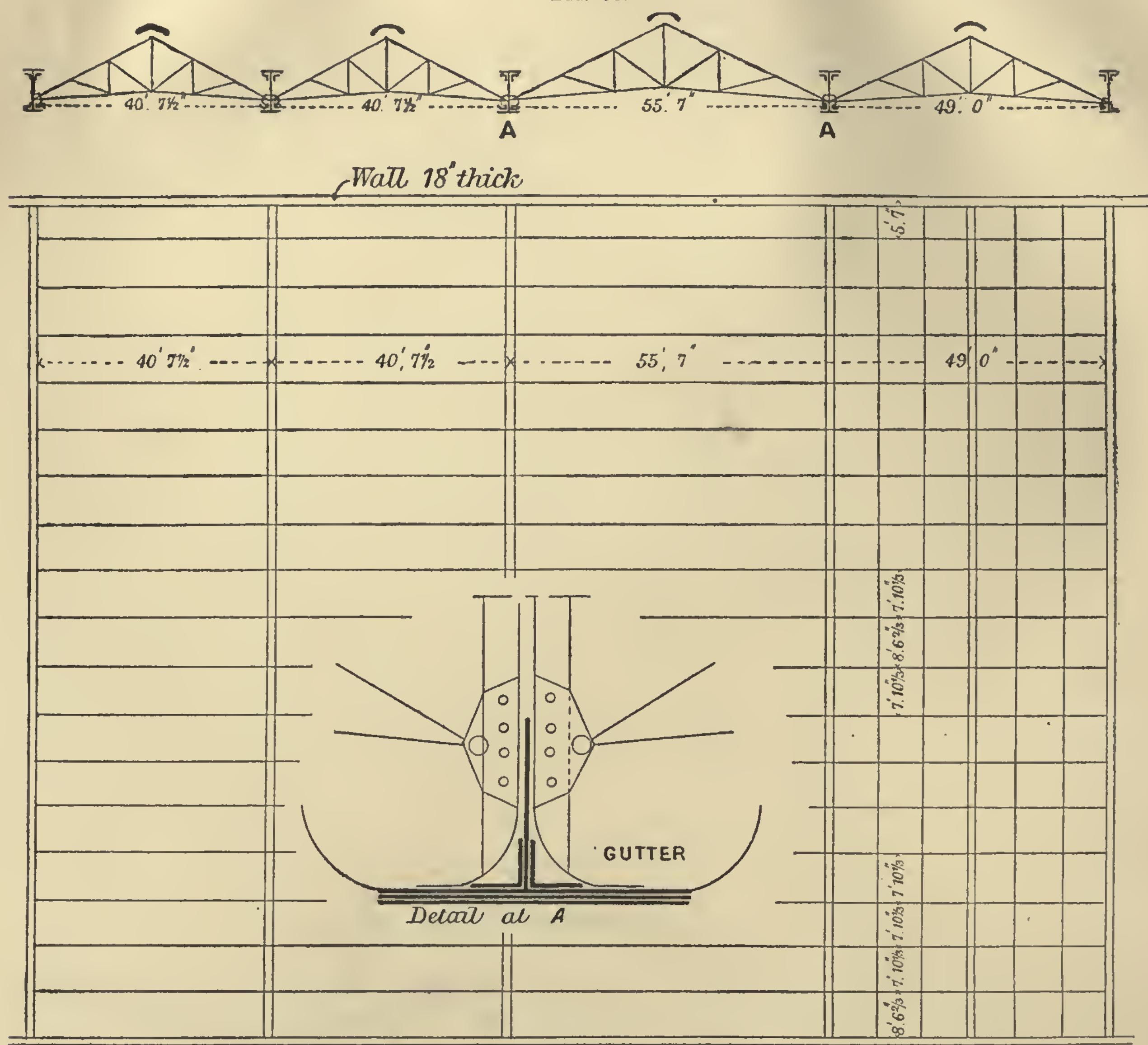
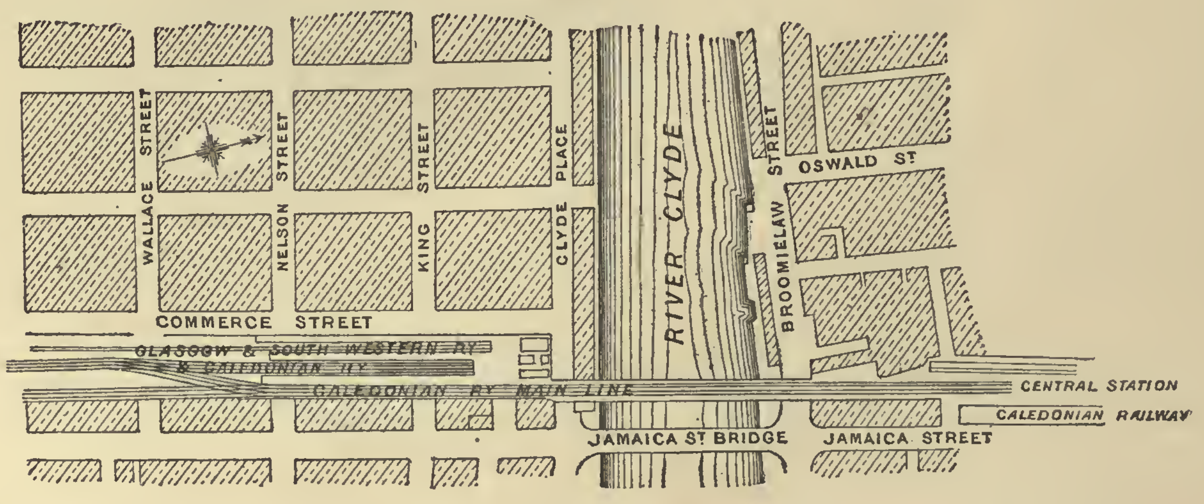


Fig. 67



possible, is that less harm is done to the ironwork by the action of the weather than that resulting from the fumes given off by the locomotives.

As shown by Figure 67, it will be seen that the Bridge Street Station and the Central Station, Glasgow, are situated upon the opposite sides of the river Clyde. Plates 5 and 6 illustrate the

Bridge Street Station roof, and Plates 7 and 8 the Central Station roof. Both stations were built by Messrs. P. and W. Maclellan, Trongate, Glasgow (see pages 6 and 7).

Plates 9 and 10 illustrate the Carlisle Station roof, constructed by Messrs. Arrol and Co., of Dalmarnock Ironworks, Baltic Street, Glasgow. The roof consists of 24 transverse girders, two of which form the two end screens. The columns come in the central platform under the junction of the girders as shown upon Plate 9, there being 8 columns at one end and 7 columns at the other end of the station, the intermediate nine girders being supported by the refreshment-room building, situated in the central platform. There is a bridge leading over the rails to the booking-office from the central platform (see page 7).

The form of truss shown in Figure 6 (page 2) is adopted at Euston Station, London, in two spans of 62 feet 6 inches over the two arrival platforms, one span of 26 feet 6 inches over the cab drive nearest Seymour Street (arrival side), one span of 34 feet over the cab drive (arrival side). There are also other spans of 26 feet 6 inches, two of 40 feet, one being over the east departure, one of 29 feet over local lines, one of 39 feet, one of 43 feet 6 inches, and another of 49 feet 6 inches over the west departure (Old London and Birmingham Station).

The roof over Amiens Street Station, Dublin, forming the terminus of the Great Northern Railway of Ireland, is formed in two spans of 60 feet, with principals as in Figure 6 (page 2), 6 feet $10\frac{1}{4}$ inches apart. There are two end gables, and the length of the roof is 592 feet $3\frac{1}{2}$ inches. The depth of truss is 13 feet, rise of lower tie in the centre of the span 1 foot 6 inches above the springing line. This roof was designed by Mr. W. H. Mills. The roof over the Central Station, Leeds (Great Northern Railway), described upon page 10, was extended in 1885.

Plates 11 and 12 illustrate the roof over the Leeds Corn Exchange, constructed by Messrs. Butler and Sons, of Stanningley Ironworks, over an oval building 63 feet 9 inches by 43 feet 9 inches.

Plate 13 illustrates the York Station (North-Eastern Railway), built by Messrs. Butler and Sons, Stanningley Ironworks, near Leeds. The general appearance is shown in the frontispiece to this book.

Plates 14 to 17 illustrate the roof over St. David's Station, Exeter (see page 9).

Plates 18 to 20 illustrate Penzance Station roof, built by the late firm of Messrs. Vernon and Ewens, Cheltenham (see page 9).

Plate 21 shows the roof over the Retort House of the Dublin Gasworks, designed by Mr. Jabez Church (see page 10).

Plates 22 and 23 illustrate the Swansea Railway Station, constructed by the late firm of Messrs. Vernon and Ewens, of Cheltenham (see page 10).

Plate 24 illustrates the roof over the Drill Hall, Port Elizabeth, built by the Thames Ironworks Company, Blackwall. The distance between the centres of the principals is 10 feet $6\frac{1}{2}$ inches.

Plates 25 and 26 illustrate the Victoria Station roof (London Brighton and South Coast Railway) (see page 11).

Plate 27 illustrates the roof over the Joint Line Station (North-Eastern Railway and London and North-Western Railway) at Leeds, built by Messrs. Butler and Sons, Stanningley Ironworks, near Leeds (see page 12).

The roof at the Nitheroy Gasworks, Brazil, described upon page 12, was made by Messrs. Handyside and Co., Derby.

The roof over the Westland Row Station, forming the Dublin Terminus of the Dublin Wicklow and Wexford Railway, is formed of trusses of the type shown in Figure 3 (page 2). There are two spans, one 66 feet by 245 feet long, the other 90 feet by 485 feet long. The large span of 90 feet has a depth of truss equal to 12 feet with a rise of tie-rod above the springing line equal to 12 feet, giving a total rise of 24 feet above the horizontal supports. In the junction of the spans, columns are spaced 40 feet apart (centres), and the principals 13 feet 4 inches (centres), i. e. one principal over each column, and three bays of glass between the columns. The roof was designed by Mr. John Chaloner Smith, the Engineer to the Railway Company.

The New Street Station at Birmingham, described upon page 13, has been considerably enlarged by the addition of two main spans on the south side, over the space formerly occupied by Great Queen

Street. These spans consist of principals of the type shown in Figure 11 (page 3), 58 feet 2 inches to 67 feet 6 inches (centres) placed 12 feet apart. The depth of the rib from the top of truss to arch of tie averages 14 feet, and the arch at the tie rises 6 feet above the springing.

Plate 28 illustrates the roof over the Cannon Street Station, shown on Plate 70, and Plate 29 the roof over the Charing Cross Terminus Station of the South-Eastern Railway, both of which are described upon pages 13 and 14.

Plate 29 also shows the roof over the Royal Aquarium, Westminster, described on page 21, and shown upon Plate 70.

Plates 30 and 31 illustrate the roof over the Leeds Exhibition, made by Messrs. Handyside and Co., of Derby, and described upon pages 29 and 30.

Plates 32 to 34 illustrate the London Bridge Terminus Station roof of the London Brighton and South Coast Railway, described on page 14. The length of the station is 660 feet, consisting of 5 bays of 36 feet, and 10 bays of 48 feet. The width equals 266 feet, consisting of 88 feet central span, together with 87 feet and 91 feet side spans.

Plates 35 and 36 illustrate the roof over the Blackfriars Passenger Station of the London Chatham and Dover Railway, described upon page 14. Although this roof was removed when the Blackfriars Railway eastern bridge was built and the St. Paul's Station constructed upon the Middlesex side of the river, the design of the bold and striking octagonal cast-iron columns are well worthy of study and imitation, on account of their simplicity, solidity, and elegance. Columns of the same design are to be seen at Ludgate Hill Station (L. C. & D. R.).

The type of truss adopted for the main roof over St. Paul's Station (London Chatham and Dover Railway), designed by Mr. J. W. Barry, is shown by Figure 64, page 40. The trusses are 126 feet span, 15 feet 10½ inches apart. There are nine of these trusses, including the screens. The inclined rafter consists of an ordinary wrought-iron flanged girder 9 inches deep, and is braced as shown in Figure 64, the struts being formed of wrought-iron tubes of 2½, 3½, and 5 inches diameter respectively, bolted to a casting at the connection with the tie-rods. The central tie-rod rises 2 feet 4 inches above the springing line at the centre, and 1 foot 9 inches above the springing line at its junction with the inclined side ties of the truss. The depth of the truss from the intersection of the inclined rafters at the ridge to the central tie is 31 feet 6 inches, or one-fourth of the span. The purlins have a uniform depth of 1 foot 4 inches, and are placed 7 feet 10½ inches apart. They are formed of lattice-work, and made to act as continuous girders framed to the rib at the connections. The diagonal wind ties pass from corner to corner over the area covered (127 feet by 126 feet) underneath the purlins and over the top of the rafters. The sash bars are of wrought iron.

Figure 65, page 40, illustrates the roof over the Leicester Passenger Station, designed by Mr. James Fraser, Architect, and Messrs. John Fraser and Sons, Engineers. The span between the centre of girders is 66 feet 3½ inches. The T-iron purlins are 5 inches by 3 inches by $\frac{3}{8}$ inches, placed over each radial bar on the crescent principals, about 8 feet 8 inches apart. The angle-iron purlins are 4 inches by 2 inches by ¼ inch placed two in each bay between the T-iron purlins. The T-iron purlins are 12 feet 6 inches from centre to centre of crescent principal. Some are trussed 10½ inches deep, and some left untrussed. The angle irons to the top and bottom members of the crescent principals are 3 inches by 6 inches by $\frac{7}{16}$ inch. The radial and diagonal bars are 4¼ inches by ½ inch.

Plates 37 and 38 illustrate the roof over the Lime Street Station, Liverpool. Both this roof and the roof over the Woodside Station, Birkenhead, were built by the Bridge and Roofing Company (Limited), Darlaston, South Staffordshire, and are described upon pages 14 and 15.

In the stress diagrams shown upon page 17, the first diagram shows the roof truss fixed upon the side exposed to the wind, and the second diagram shows the roof truss fixed upon the lee-side.

Plates 40 and 41 give the general arrangement and details of construction of the roof and columns designed by the Author for Messrs. Arthur Cawston, of Spring Gardens, London, and Joseph Graham, of Guildhall Offices, Carlisle, the architects for the new markets now being erected by the Corporation of Carlisle; Messrs. Hodgson and Co., of Workington, are the general contractors,

and Messrs. Robertson and Co., of Workington, are the contractors for the ironwork. Owing to the peculiar shape of the ground upon which this building is to be erected and the arrangement of the plan by the architects (see Plate 40), some difficulty was encountered in designing the roof, although for the most part it is symmetrically arranged, that part over the fish market presenting the least uniformity. The market is roofed over in three spans of 70 feet 6 inches, with trusses having a rise of 18 feet 9 inches from the springing to the back of the rib. The back of the rib is struck from a radius of 44 feet 6 inches, and the underside of the rib is struck from radii of 41 feet 8 inches, 58 feet, and 11 feet 6 inches respectively. The principle of construction is that of a tied arch which presents a light and elegant form of truss having few parts, and no thrust on the walls or columns, except that produced by wind pressure. In order to obtain as little obstruction in the market as possible, the number of columns was required here to be as few as possible. Instead of a column being placed under each main truss, every alternate truss is supported on a column, and the intermediate main trusses are carried on girders supported between the columns. The columns are 39 feet 6 inches apart, and the main trusses 19 feet 9 inches apart. The bays between the main trusses are spanned by the main purlins which carry intermediate ribs, the spaces being further divided up into convenient sizes for the boarding by secondary purlins 9 feet 10½ inches long carried on the main and intermediate ribs. The ribs at the hipped end of the truss are simply curved girders having no thrust, and are supported at the centre on a specially designed truncated truss (see Plate 41). The columns which are designed to resist the horizontal thrust resulting from the wind pressure are (owing to the small number) exceptionally strong, and are firmly bolted down by strong anchorages to massive concrete foundations. The inside of the columns are made use of for conveying the rain water from the gutters, and are protected by a lining of concrete surrounding a wrought-iron pipe which connects the gutters with the drains. The conditions specified for the ironwork employed in this contract are given upon pages 76 to 78.

Plates 42 to 44 illustrate the roof over the West-end Terminus Station of the London Chatham and Dover Railway, described upon pages 18 and 19, and included in the roofs shown on Plate 70. The ironwork was supplied by The Horseley Company (Limited), of Tipton, Staffordshire. The ironwork for the Central Station roof, Liverpool, described upon page 19, was supplied by Messrs. Handyside and Co., Derby.

Plate 45 illustrates the roof over the Queen Street Station, Glasgow, in which steel tie-rods were employed (see remarks made by he Author at The Institution of Civil Engineers, 'Minutes of Proceedings,' vol. 69, page 26). The iron and steel work was constructed by Messrs. P. and W. Maclellan, of Trongate, Glasgow, and is described upon page 19.

Plate 46 illustrates the roof over the Broad Street Station, London, described upon page 18. There are twelve bays in this roof, of 37 feet each, which, in addition to one bay of 16 feet 9 inches, make a length of 460 feet 9 inches.

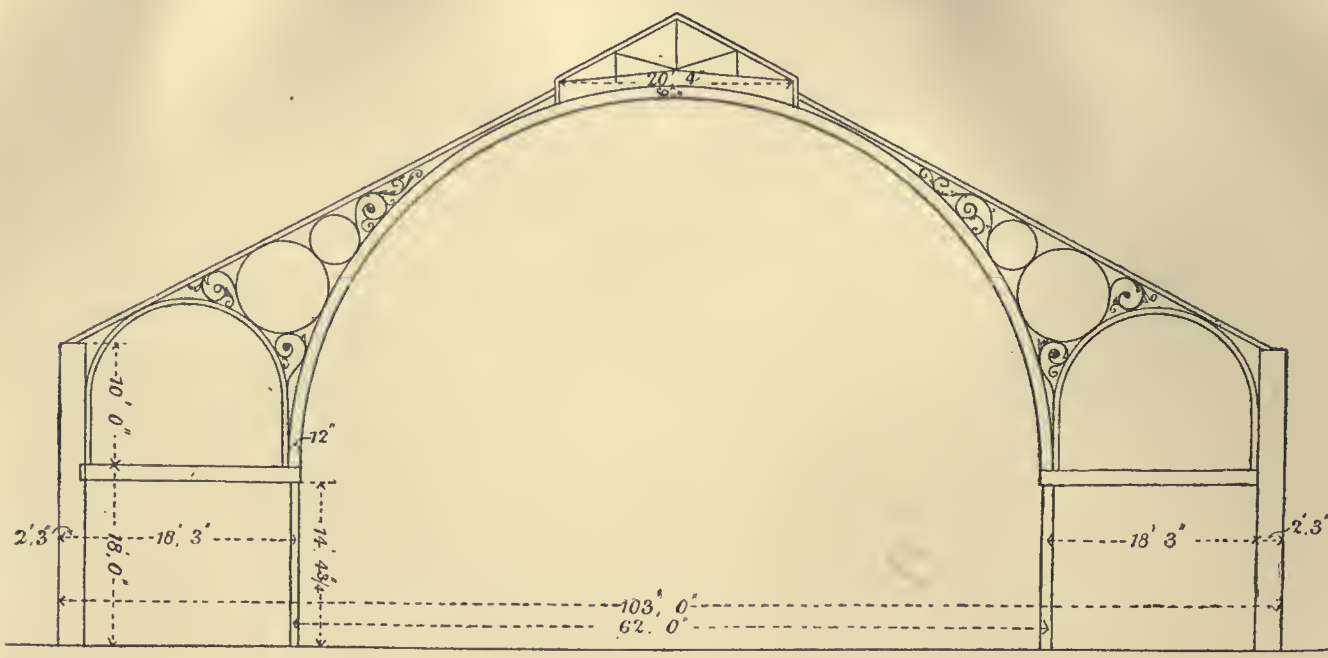
In the Fenchurch Street Station, described upon page 13, there are 29 main principals forming 29 bays including the end screen, the roof being closed at the other end by a wall.

Plate 47 gives a plan of the Preston Railway Station, the roof over which is similar in construction to that over the Broad Street Station, London. The strut in this truss forms the upright of the purlin, which is placed intersecting the main principal at the middle vertical of the three vertical members, shown upon each side of the centre line of the truss.

The width of the High Street Station, Kensington, between walls is 90 feet 6 inches, and the principals described upon page 20 are 22 feet apart. The intrados of each arch in the roof over the Paddington Railway Station forms an ellipse. The dimensions are given upon page 22. The ironwork for the Royal Agricultural Hall at Islington was made by Messrs. Handyside and Co., Derby, and is described upon page 22. Another instance of connecting the side arches to the central arch (as shown in Figure 36, page 23) in such a manner that the whole forms a compound structure, transmitting part of the thrust from the central arch through the side spans to the walls, is shown in Figure 68, illustrating the roof over the Norwich Agricultural Hall designed by Mr. John B. Pearce. The outline of the roof is also shown upon Plate 70, and covers a space 123 feet long by 103 feet in breadth. There are five main principals, 62 feet span, placed 24 feet apart, which are surrounded

by a gallery floor carried upon girders 10 inches by 5 inches, the central arch of each principal springing from the top of a cast-iron column about 14 feet 6 inches above the floor.

Fig. 68.



A plan of the roof, as described by Figure 32, page 21, in its re-erected position at Battersea, is given in Figure 58, page 38, and the outline of the structure is also shown upon Plate 70.

Plates 47 and 48 illustrate the roof over the Middlesborough Station, made by Messrs. Handyside and Co., Derby, and described upon page 23.

Plates 49 to 51 illustrate the roof over the Great Hall at the Alexandra Palace, Muswell Hill, made by Messrs. Handyside and Co., Derby, and described upon page 23.

Plate 52 shows the form adopted both in the old and new roofs covering the Great Northern Railway Terminus Station at King's Cross. The roof over the Goods Station at Bradford, which is similar in construction to the new roof at King's Cross, consists of 17 main ribs, forming 16 bays. The new iron roof at King's Cross was erected by Messrs. Handyside and Co., of Derby, and is described upon page 24.

Plates 53 to 56 illustrate the roof over the Midland Railway Terminus Station at St. Pancras, which is described upon page 25, and shown in outline upon Plate 70. The calculation of strains is shown by diagram upon page 52, and described upon pages 57 to 63. The ironwork was made by the Butterley Iron Company, Derby.

Plates 57 and 58 illustrate the roof over St. Enoch's Terminus Station, Glasgow. The ironwork was made by Messrs. Handyside and Co., of Derby, and is described upon page 25. The ironwork for the Manchester Central Station (Plate 11) was also made by Messrs. Handyside and Co., and consists of a roof 210 feet span, 550 feet long. In the St. Enoch's Station the members forming the framework of the screen (Plate 57) are radial, whereas in St. Pancras Station (Plate 56) and the Central Station, Manchester (Plate 11), they are vertical. Radial members form the best connection with a curved rib, but are awkward when the lower member of the screen is horizontal as in the Manchester and St. Pancras roofs. The roof over the Drill Hall at Derby, described by Figure 43, page 26, was also made by Messrs. Handyside and Co. The roof is formed in ten bays, with nine principals (Figure 43), and enclosed by two end walls. The roof looks rather low compared with the span from the inside of the building.

In the reading-room at the British Museum, the construction of which is described upon page 28, light is obtained from twenty circular-headed windows, 27 feet high by 12 feet wide, inserted at equal intervals round the dome at a height of 35 feet from the ground, and the quantity of glass

used altogether in the roofing amounts to 60,000 square feet. The springing of the dome is 24 feet from the floor of the reading-room, and the ground is excavated 8 feet below this level. The excellent ventilating arrangements were carried out by Messrs. Haden and Sons, of Trowbridge. The new reading-room contains 1¼ million cubic feet of space, and the surrounding libraries ¾ million cubic feet. The libraries are 24 feet in height, with the exception of the portion which runs round the outside of the reading-room, which is 32 feet high. The roof is formed into two separate spherical and concentric air-chambers extending over the whole surface, one between the internal visible surface and the brick vaulting, and the other between the brick vaulting and the outside covering. The former serves to carry off the vitiated air from the reading-room, being conducted to this inner chamber partly through circular apertures fixed over the soffits of the windows, and partly through openings provided around the lantern in the top of the dome; while the object of the outer air-chamber is to maintain an equalisation of temperature during extremes of heat and cold out of doors. All the windows, skylights, and lanterns throughout the roof are made double, with the object of obviating the effects of condensation. The supply of fresh air is obtained from a shaft 60 feet high built on the north side of the north wing, about 300 feet distant, communicating with a tunnel or subway which has branches or loop lines, fitted with valves for diverting the current either wholly through special heating apparatus, or through the cold-air flues, or partly through either as occasion may require. Thus in the summer a continuous current of fresh air can be forced into the room by means of a steam engine and blower, while in winter the air is first warmed by the heating apparatus. In winter the vitiated air can find its own way out, but in summer, steam pipes placed at the summit of the roofs and dome are heated to help the extraction of the foul air when the external and internal temperature is unfavourable for the purpose. By this arrangement the succession of hot and cold blasts are avoided, and the air is renewed imperceptibly.

The reading-room contains ample and convenient accommodation for three hundred readers, and the air-channels are calculated to admit a supply of fresh air for five hundred persons at a rate of 10 cubic feet per minute, and at a velocity not exceeding one foot per second. The pedestals of each reading-table form tubes communicating with the air-chamber below, which is 6 feet high, and occupies the whole area of the reading-room. It is in this area that the hot-water pipes are fitted and arranged in radiating lines. The air is distributed in the room by means of the central framework to each table, which forms a screen between one reader and the opposite occupant, and discharges the fresh air through a longitudinal wirework above the level of the heads of the readers. A tubular foot-rail also is fixed from end to end of each table, which may have a current of warm air passed through it at pleasure, so as to be used as a foot-warmer if desired. By an arrangement of valves, the air may be admitted by the end pedestal of each table only if required. The book-shelves are also well ventilated. The catalogue tables in the centre of the room contain central screens, which likewise form air-distributing channels immediately under the lantern. The shelves surrounding the reading-room are formed of galvanised plates edged with wainscot, and covered with russet-hide leather, each having a book-fall attached. They are fitted at each end with galvanised iron covered with leather, and wadded so as to prevent any book sustaining damage while being taken out or replaced. Between these pads the skeleton framing of the cases forms an aperture by which a current of air is continually passing. Further ventilation is produced by means of a perforated floor in the gallery avenues. These galleries are 8 feet wide, and are supported by the galvanised iron uprights or standards forming the back framework of the bookcases, the central six feet in width of the floor being perforated. In all cases except against the external walls the bookcases are double, the books being placed on both sides and separated by a longitudinal open screen formed of lattice ironwork.

In carrying out plans for ventilation it must be remembered that no satisfactory provisions will be obtained unless apertures for the ingress of fresh air are provided, in addition to those for the egress of impure or vitiated air.

The fan is the principal instrument employed in mechanical ventilation, but is not suitable to all classes of public buildings. In designing a fan, it should be remembered that a large fan and low speed is generally preferable to a small one and high speed, chiefly on account of the vibration

caused by gearing running at great velocities. The motive power may be either steam, water, or a weight, which can be wound up as occasion may require; but steam is more prompt in its action than water.

It will be admitted that (1) any scheme of ventilation to be popular and useful must be simple; (2) that the more natural and the less artificial the system the better; (3) that where mechanical applications are resorted to they should be self-acting to as great an extent as possible; (4) that where machinery is absolutely essential to work the system adopted, it should be in duplicate, in case of accident or repair, and the control of the arrangements must be always placed in properly qualified hands.

In the roof over the reading-room of the British Museum, in order to guard against the consequences of an avalanche of snow falling from the dome (140 feet diameter) on to the surrounding roofs, the building has been carried up outside perpendicular to such a height above the springing of the arch as to form a gallery 9 feet in width provided with proper outlets, by which the snow is intercepted.

Plates 59 and 60 illustrate the roof over the Royal Albert Hall at Kensington, described upon page 28. The apparatus for the ventilation and warming was designed by Mr. W. Phipson, and carried out by him under the direction of Major-General Scott, the architect to the building. The form of the hall is nearly a true ellipse in plan; the span of the roof is 219 feet 4 inches by 185 feet 4 inches, and the span of the outer walls is 272 feet by 238 feet. The arena is 15 feet below the level of the Kensington roadway, and the height from the arena to the springing line of the roof is about 135 feet, and to the top of the lantern surmounting the roof about 150 feet. Two air-shafts are provided, having their apertures at some distance from the hall, and the air in passing through them is strained by fine sieves and washed by means of water-sprays; it is then driven into the main air-chambers by means of two fans, each 6 feet in diameter, fixed at the orchestra end of the hall and worked by two direct-action steam-engines of seven horse-power. Each of these fans has four blades, and are together capable of forcing 3,500,000 cubic feet of fresh air per hour into the building. These main air-chambers are placed, one under the arena, another under the amphitheatre stalls, a third under the main corridors, and contain about 26,000 square feet of heating-pipes, 4 inches in diameter, by means of which the air may be warmed in winter to the required degree prior to its conduction, by means of air-flues into every part of the building. By an arrangement of valves a direct supply of fresh air may be distributed into the hall without its having to pass through the various heating-chambers. Perforations are provided in the arena floor, in the rises of the amphitheatre stalls, and by vertical air-flues formed in the walls with apertures on each floor for its circulation throughout the hall, and its escape is provided for in the centre of the roof by a shaft which is carried some feet above the highest part of the roof, in which the current is maintained by the use of about 1260 gas jets. From the experience obtained in the working of this apparatus, it is found that a temperature, 56° to 58° Fahr., can be easily maintained during the winter months within the hall. The heating-surface in the three continuous heating-chambers is arranged in distinct coils, the steam being supplied to them from two 30-horsepower boilers.

The Circus roof at Paris, belonging to the Hippodrome Company, is formed immediately within the steps surrounding the arena, in an iron belt, 50 feet wide, leaving a central space of 175 feet by 57 feet. It is this central space which can be left open to the sky for the freedom of vitiated air or closed at will by the aid of a special movable covering. This movable covering is divided into two parts, each of which can be moved on one side longitudinally, over fixed outside roofings, by travelling on wheels worked by mechanical power, and thus, when open, both halves of the central portion completely disappear from the audience inside the hall. The fixed covering springs at a height of 52 feet above the ground, and abuts against an oval centre, 72 feet above the ground. It is supported at its circumference by twenty columns, and at the summit rests against central beams, which form the circumference of the movable roof. Each movable half weighs 24½ tons. The beams forming the boundary of the movable portions, when closed, are prolonged

longitudinally, and are supported by four pillars, 72 feet high, for the purpose of supporting the movable portion when open. Between the roofing over the steps and the fixed belt surrounding the arena, there is a vertical space, 16 feet in height, closed by glass windows, and the curved parts at the two extremities of the oval are continued round without the introduction of any special polygonal framework. (See Figure 53, page 32.)

The Sliding Roof at the London Pavilion, Piccadilly Circus, is arranged similar to that at the Canterbury Music Hall, Lambeth (Figure 52, page 32), and is 30 feet 4 inches long by 15 feet 3 inches wide sliding over lattice girders, designed by Mr. J. E. Saunders, Architect, and erected in 1885.

Plates 61 to 63 illustrate the roof over the Great Eastern Railway Terminus at Liverpool Street, described upon page 31, and shown upon Plate 70.

Plate 64 shows the roof over the Norwich Thorpe Station of the Great Eastern Railway, designed by Mr. John Wilson, M. Inst. C.E. The main roofing of the station is shown by two general views, and the detail of the attachment of the main girders to the columns show the arrangement of utilising the latter for rain-water stack pipes. The general plan of the station shows the three platforms which are covered over for a portion of their respective lengths by awnings in iron, zinc, and glass, supported in the case of the two main platforms upon a double row of ornamental cast-iron columns, $5\frac{1}{2}$ inches diameter. The east platform is covered in like manner, but supported by a single row of columns, and an outer wall. Details showing the method of construction, accompany a plan of a portion of the awnings over main platforms. This plan, half of which shows the zinc and glazed roof, is subdivided in order to show the boarding beneath the zinc, and the arrangement of the cantilever purlins The 12 feet span transverse principals between the columns are similar in construction to the 23 feet span, longitudinal ones (half principal of which is shown), and the cantilevers in iron, supporting balance girder, are reproductions of the half transverse principal, with the top and bottom members elongated 2 feet, and connected to a balance girder, as shown by section at G G.

Plates 65 to 68 illustrate the details of the roof over Olympia, Kensington, designed by the Author with Mr. Max am Ende, M. Inst. C.E., of Westminster, acting as joint engineers for the late Mr. Henry E. Coe, the original architect to the National Agricultural Hall Company. At his decease Mr. James Edmeston was appointed architect, and the structure has been made and erected by Messrs. Handyside and Co., of Derby, under the superintendence of the engineers and general direction of the architect. Messrs. Lucas and Son were the general contractors, and the hall was opened in December 1886. Plate 65 shows the plan of the Great Hall which covers an area of about $2\frac{1}{2}$ acres. The whole building stands upon $6\frac{1}{4}$ acres of ground. There are three entrances, a railway entrance upon the east side, a carriage entrance upon the south side at the back of the orchestra, and a goods entrance upon the west side. It will be observed that the various parts are grouped together in the construction of the roof by lattice members whereby great economy of material has been effected over the usual solid plate system. The manner in which the horizontal thrust of the main roof and the horizontal pressure of wind is taken up by the structure is novel. At the top of the roof over the side gallery the foot of the semicircular arched rib is divided into two parts, one part proceeding down in a vertical direction, and the other following the slant of the lean-to roof over the gallery and then developed into a braced frame shown upon Plate 67. The whole gallery acts as an abutment to the arch, the traffic on the gallery floor and upon the ground floor beneath it passing through openings in this abutment. The inner portion of the gallery is carried by a cast-iron column (see Plate 66), which has a ball-and-socket joint at each end, and supports in its pivot joint, also the greater part of the weight of the circular roof. Thus the bending moment on the column is obviated. Both continuous and independent girders are used in the floor and in the roof according to considerations of economy. The main purlins which run from screen to screen are continuous girders, and they communicate a portion of the wind pressure from one screen to the other. The longitudinal inner floor girders under the north and south galleries which come in line with the inner row of columns, and the facia girders in line with the longitudinal pivoted

columns, also are continuous girders. The stability of the ironwork is independent of the surrounding walls. Each end screen, as shown in plan upon Plate 66, is formed of a ridge and furrow construction, whereby the appearance of the usual heavy horizontal members in a gable screen is avoided.

Plate 65 shows the outside elevation of the wind screen, and the transverse section indicates its position with reference to the galleries and ground floor. The intermediate purlins in the main roof are placed in a radial direction between the main purlins, and in a tangential direction over the main purlins, thus both taking the weight of the covering and resisting its tendency to slip down the roof.

Plate 67 shows the details of the glass and zinc (No. 15 gauge) connections, upon Helliwell's systems, and Plate 68 shows the outside views of the building, No. 1 upon the south side, Nos. 2 and 3 upon the east side, No. 4 the interior view of the wind screen, and Nos. 5 and 6 the inside arrangements temporarily erected for the Paris Hippodrome Company. The cost of the ironwork as erected was 26*l.* to 27*l.* per square of 100 super. feet.

Plate 69 illustrates the roof over the Bradford Exchange Station, erected in two spans by the Lancashire and Yorkshire Railway Company and the Great Northern Railway Company. The details selected are those relating to the skylight and radial screens. The stanchions under the screens are made of wrought iron, and are fitted to the end columns so as to act as an abutment to the horizontal braced girder to take the wind pressure upon the screen, the longitudinal girders between the columns which support the intermediate ribs being at a higher level. The length of the roof between the screens is 430 feet, the span of roof 100 feet, the distance apart of the main ribs 25 feet. Mr. William Hunt, M. Inst. C.E., the engineer to the Lancashire and Yorkshire Railway Company, designed the roof, and the contract has been let to Mr. E. Garbutt, of Liverpool, the ironwork being sublet to Messrs. De Bergue and Co., of Manchester.

Plate 70 gives a general comparison of the vertical area occupied by certain well-known roofs, (1) over large buildings, (2) over various metropolitan railway stations.

Name of Roof.	Total transverse width.	No. of spans.	Main span.	Clear height above floor or rail level.
	ft. in.		ft. in.	ft. in.
Crystal Palace, Sydenham, Centre Transept ..	104 0	One	104 0	160 0
St. Pancras Station, Midland Railway	240 0	One	240 0	100 0
National Agricultural Hall, Kensington	250 0	One, with side galleries	170 0	99 7½
Royal Agricultural Hall, Islington	220 0	One, with side galleries	125 0	70 0
Victoria Station, L. C. & D. R.	256 4	Two	129 0	63 6
Derby Market Hall	111 6	One, with side galleries	86 6	59 6
Paddington Station, G. W. R.	240 6	Three	102 0	54 7
Royal Aquarium, Westminster	80 0	One, with side galleries	36 0	49 6
York Station, N. E. R.	234 0	Four	81 0	45 0
Liverpool Street, G. E. R.	314 0	Four	109 0	62 0
Cannon Street, S. E. R.	190 4½	One	190 4½	79 6

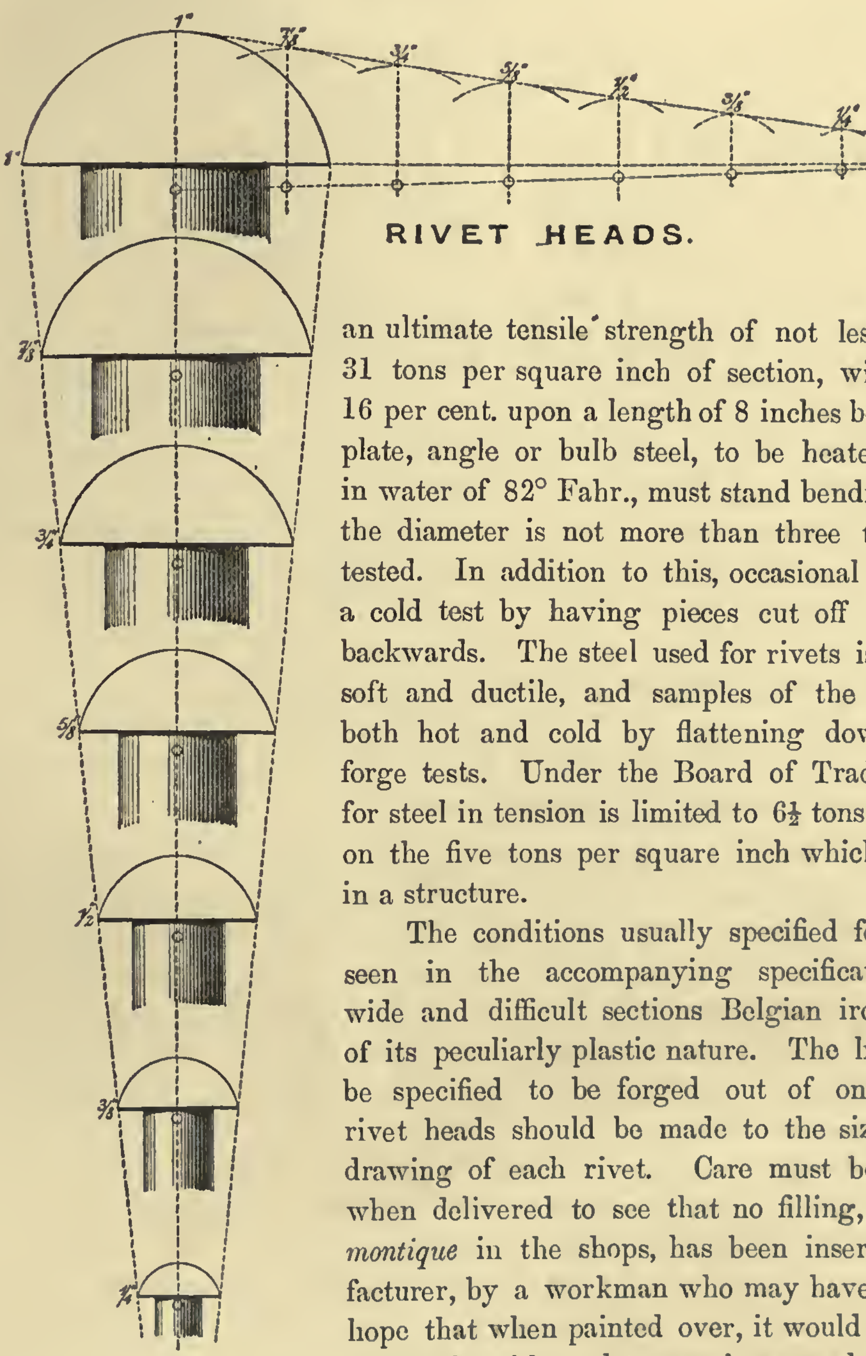
Tests.

There does not exist so much difference as formerly between the prices of iron and steel, and hence steel is now being rolled into a larger variety of sections. With roofs of small span the weight of the component parts is not sufficiently great to effect any economy by the substitution of steel for iron, but in large spans the saving of expense would be sufficient to recommend its adoption, as presenting a lighter appearance than iron of equal strength. Very great differences may arise from the means employed in testing the material to be used, and allowance must be made for sample material and that which is obtained promiscuously in the market. It is advisable that the name of the manufacturer and the distinguishing number of the bar or plate should be furnished in each case.

The length of 8 inches for the testing of the tension in bars is usually employed in this country, and 200 millimetres (7·87 inches) upon the Continent.

In specifying tests it is necessary to define the section of the specimen. Considerable differences

of opinion exist as to the comparative advantages of specifying an *elongation* test or a *contraction in area* test, or both. Both tests serve to prove the ductility of the material, and are indicative of the amount of fatigue that a bar would bear before rupture, as well as showing the capability of the bar to adapt itself to changes in cross-sectional area. The specification for the National Agricultural Hall roof (pages 74 to 76) prescribed the former. The specification for the Carlisle Corporation Market roof (pages 76 to 78) prescribed the latter. Whether one or both conditions of test are specified, it is necessary to demand that the steel or iron to be employed shall be well and cleanly rolled to the full sections shown upon the drawings or described in the specification, and that the finished work shall be free from scales, blisters, laminations, cracked edges, or imperfections of any kind. The cost of tests are to be met as provided for in the conditions of contract.



RIVET HEADS.

The tests observed under Lloyd's regulations for steel are that strips cut lengthwise or crosswise of the plate, and also angle and bulb steel, shall have an ultimate tensile strength of not less than 27 and not more than 31 tons per square inch of section, with an elongation equal to at least 16 per cent. upon a length of 8 inches before fracture. Strips cut from the plate, angle or bulb steel, to be heated to a low cherry red and cooled in water of 82° Fahr., must stand bending double round a curve of which the diameter is not more than three times the thickness of the plates tested. In addition to this, occasional angle bars are to be subjected to a cold test by having pieces cut off and bent flat and then doubled backwards. The steel used for rivets is specified to be of special quality, soft and ductile, and samples of the rivets are tested by being bent both hot and cold by flattening down the heads and by occasional forge tests. Under the Board of Trade regulations the working strain for steel in tension is limited to 6½ tons per square inch, or 30 per cent. on the five tons per square inch which is generally prescribed for iron in a structure.

The conditions usually specified for wrought and cast iron can be seen in the accompanying specifications (pages 74 to 78). For wide and difficult sections Belgian iron commends itself upon account of its peculiarly plastic nature. The head and body of all bolts should be specified to be forged out of one piece of rod or bar iron, and rivet heads should be made to the sizes shown upon the accompanying drawing of each rivet. Care must be taken to test finished ironwork when delivered to see that no filling, such as what is known as *beaumontique* in the shops, has been inserted in the absence of the manufacturer, by a workman who may have turned out imperfect work in the hope that when painted over, it would not be detected. By striking the ironwork with a hammer in several places, such deception may be at once detected, but happily the cases of such dishonesty are not numerous. No casting should be permitted to be painted, until it has been inspected: and care should be taken that the metal is properly run from the cupola, at the manufacturer's works, without any admixture of cinder. The required deflection usually specified for cast-iron test bars is intended as a precaution against brittleness.

REPORT UPON SAMPLES OF IRON CUT OUT FROM ACTUAL WORK IN THE MANUFACTURER'S YARD AND TESTED IN THE PRESENCE OF THE AUTHOR.

No.	Description.	Mark.	Maker.	Breaking weight in tons per square inch.	Reduction per cent. of original area.	Elongation per cent. of original length.	Remarks.
	Angle iron .. $6 \times 4 \times \frac{7}{16}$	N.A.	Skelton Bar Iron Co.	19·89	13·49	7·12	All fibrous and slight defective weld.
	Ditto	”	”	21·73	13·23	8·27	All fibrous (broken at shoulder).
	Angle iron .. $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	”	”	21·10	22·23	10·75	All fibrous (broken at shoulder).
	Ditto	”	”	21·41	21·40	16·37	All fibrous.
	Angle iron .. $5 \times 2\frac{1}{2} \times \frac{1}{4}$	”	”	23·22	17·06	9·12	All fibrous (broken at shoulder).
	Ditto	”	”	22·80	22·35	9·50	All fibrous.
	Plato $12 \times \frac{1}{4}$ ..	”	Fox Head & Co.	23·80	13·65	7·00	All fibrous.
	Ditto	”	”	23·66	14·20	6·62	All fibrous.
	Bar $9 \times \frac{1}{4}$ ..	”	”	21·00	19·23	9·25	All fibrous.
	Ditto	”	”	20·63	16·19	8·75	All fibrous and slight defective weld.
	Bar $5 \times \frac{1}{4}$ ..	”	”	20·63	20·00	11·25	All fibrous.
	Angle iron .. $2 \times 2 \times \frac{1}{4}$	”	”	23·00	20·40	12·50	All fibrous.
	Ditto	”	”	26·46	21·17	12·50	Nearly all fibrous.
	Bar $1\frac{1}{2} \times \frac{1}{4}$ ..	”	”	23·00	22·80	20·60	All fibrous.
	Angle iron .. $2\frac{1}{2} \times 1\frac{1}{4} \times \frac{5}{16}$	”	”	20·41	21·43	13·00	All fibrous and slight defective weld.
			15)	332·74	278·83	162·70	
			Average ..	22·25	18·59	10·82	

THE NATIONAL AGRICULTURAL HALL, KENSINGTON.

SPECIFICATION OF CONSTRUCTIONAL IRONWORK TO ROOF AND WORK CONNECTED THEREWITH (SEE PLATES 65 TO 68).

The contractor is to include in his estimate all wrought-iron, steel, and cast-iron work, for the support of the roofing and the gallery floor of the Great Hall which covers a space of 440 feet by 250 feet between walls, the cast-iron gutter on the top of the walls, the patterns for the cast-iron work, the flower ornaments fixed to the principals, the square ornaments on the lower member of the screen, the scroll ornaments and the finial at the ends of the ventilator; the drilling of all holes necessary for the fixing of the floor, and of the roof covering; the caulking with cement under all base plates and bases of the columns and stanchions, the erection, fixing, oiling, and twice covering the ironwork with two coats of approved paint.

Provide all necessary and sufficiently strong-framed scaffolding, centering, &c., for the proper and efficient carrying out of the following works and to clear away same at completion.

Provide for the use of all plant and tackle that may be required.

The contractor for the general works is to have the use of the scaffolding for the purpose of executing his own work.

The firm who execute the ironwork will have to enter into a contract with the general contractor as to the time in which they will execute the work, and such contract shall provide for such conditions, penalties, and responsibilities as may hereafter be approved by the architect.

The whole of the ironwork is to be done under the direction and to the satisfaction of the architect or his engineers.

All wrought-iron parts are connected by rivets, with the exception of the sash bars, which are fixed by turned bolts; the riveting on the site should be restricted to those junctions which cannot be made at the manufacturer's works. The rivet holes may be either punched or drilled, but the

rivets must fill the holes completely, and those at the junctions, to be made on the site, must be rimered so as to fit each other exactly.

The rivet heads should be cup-headed.

All butt joints must be planed.

The bent flanges of the ribs and girders must show no undulating edges, and the edges of the angle irons must be trimmed if necessary.

The visible ends of bracing bars and angle irons generally cut off under angles of 45 degrees or any other angle must be neatly finished; special care in this respect must be taken with the girders and casings facing the centre of the building and with the gallery railing.

The castings must be clean and free from any fault, the thicknesses must be uniform where they are shown to be so on the drawings.

The bolt holes in the castings must be drilled or cast accurately round, of a diameter not more than one-twentieth larger than that of the bolts.

The caps and bases of the columns and other portions required must be planed to a true and even face.

The whole of the ironwork will be divided into eleven classes and thirty-one batches, and the number of tests will be at least eighty-four, as specified in the following table :—

No. of class.	Description of parts.	No. of batches.	No. of tests.
I.	Abutment frames	3	6
II.	Gallery girders	3	9
III.	Main ribs	3	9
IV.	Other parts of main roof	3	9
V.	Side roof	3	9
VI.	Screens	3	6
VII.	Ventilator, balcony, gallery railing	3	6
VIII.	Wind bracing	3	6
IX.	Rivets and bolts	3	9
X.	Ladders	1	6
XI.	Cast iron	3	9
			84

General Conditions of Testing.

The architect or an engineer appointed by him shall have the power of making the tests with test pieces cut out of the finished wrought-iron work after delivery on the site.

The contractor shall advise the architect and the engineers of the delivery of every batch of ironwork, and one of them shall within seven days of the delivery of every batch, mark or attach their brand and number to the pieces to be used for testing; if they fail to do so, the respective batches shall be considered as passed. Each test piece shall have such form and sectional area as the architect or his engineer may determine, and shall contain the mark or brand of one of them.

The various batches, as specified, must be kept separate, so that disorder in their arrangement may be avoided. If any parts should be rejected they must be put in a place which will be assigned for them, and must not be removed until all parts of the *corresponding* class are erected and fixed.

They must then be immediately removed.

The making of the test pieces as well as the testing must take place on the site or at any place near the site to be approved of by the architect or one of his engineers.

The testing apparatus is to be approved of by the architect or one of his engineers.

The entire cost of the testing as well as of the removal of the rejected parts must be borne by the contractor.

All wrought-iron parts must have on an average an ultimate tensile strength of 22 tons per square inch sectional area when cut into test pieces from 8 to 18 inches net length, and about 1 square inch sectional area, and the elongation should average 12 per cent.

All rivets and bolts must have an average ultimate tensile strength of 26½ tons when cut into

test pieces from 2 to 8 inches net length, and of a sectional area not exceeding 1 square inch, and the elongation should average 14 per cent.

All steel must have an ultimate tensile strength of 31 tons per square inch sectional area when cut into test pieces from 8 to 18 inches net length, and about $\frac{1}{2}$ square inch sectional area, and the elongation should average 16 per cent.

All cast iron must carry a weight of 25 cwt. acting transversely in the centre of a bar 2 inches deep, 1 inch wide, and 42 inches long, and when supported on edges 36 inches apart the permanent deflection should be $\frac{5}{16}$ inch.

The test bars are taken from the runnings of each batch, and they are planed to a rectangular section of the above dimensions.

Each piece out of which a test piece has been cut must be replaced, and if the test shows an insufficient result the whole part will be rejected.

For every test showing an insufficient result two additional tests will be made, and the whole batch out of which the test pieces are taken will be rejected if a certain number of tests according to the following table are insufficient.

A batch will be rejected if among 12 tests :—	Wrought-iron bars and plates.	Rivets and bolts.	Steel.	Cast iron.
	Tons.	Tons.	Tons.	Cwt.
6 show an ultimate strength or breaking weight less than	22	$26\frac{1}{2}$	31	25
4 tests do. do. 4 per cent. below	these amounts.			
2 tests do. do. 8 per cent. below	the above amounts.			
	Per cent.	Per cent.	Per cent.	Per cent.
6 show an elongation (or permanent deflection) less than	12	14	16	1
4 Do. do.	10	12	14	8
2 Do. do.	8	10	12	7

All ironwork has to receive a coat of hot linseed oil after removal of all rust, the first coat of oil paint before removal from the manufacturer's yard, the second coat immediately after it has been fixed *in situ*, and after such scaffolding as is not required for the painting has been removed.

CARLISLE CORPORATION MARKETS.

Ironwork and Roofing Contract (see Plates 40 and 41).

Description of Materials.

All wrought iron must be tough, fibrous, and uniform in character. It shall have a limit of elasticity of not less than 11 tons per square inch, and shall bear the following tests :—

All plates shall have an ultimate tensile strength of not less than twenty-one tons per square inch of sectional area when tested lengthways of the grain, and eighteen tons per square inch of sectional area when tested crossways of the grain ; and shall contract in area, not less than ten per cent. at the fracture when tested lengthways, and five per cent. when tested crossways.

All angle and tee-shaped irons shall have an ultimate tensile strength of not less than twenty-two tons per square inch, and shall contract in area at the fracture not less than fifteen per cent.

The iron in all bars to be forged shall have an ultimate tensile strength of not less than twenty-four tons per square inch, and shall contract in area at the fracture not less than twenty-five per cent. Bars other than forged bars shall have an ultimate tensile strength of not less than twenty-three tons per square inch, and shall contract in area at the fracture not less than twenty per cent.

The rivets shall be of such quality that they may be bent double when cold without any sign of fracture, and the heads when heated sufficiently shall stand being hammered out to one-eighth of an inch thickness without any sign of cracking at the edge. The puddle bars shall be

thoroughly welded during the rolling and be free from all injurious seams, buckles, blisters, cinders, and imperfect edges. When nicked upon one side and bent by a blow from a sledge hammer, the fracture should appear nearly fibrous, and show but few crystalline specks.

All iron for members in tension must bend cold to an angle of 90°, without cracking, over a curve whose diameter is not more than twice the thickness of the piece.

The edges of all finished plates, and of all butt joints, shall be planed perfectly even and be square and straight.

The several pieces forming a built member of any portion of the structure must fit closely, and when riveted be free from twists, bends, or open joints. All covers at the joints must be fully connected and the ends fit true. They must be made of equal strength to the parts they connect without placing reliance upon abutting edges in the connections. The visible ends of bracing bars and of angle irons are to be neatly finished. The curved flanges of the ribs must show no undulating edges, and the edges of all angle irons and plates must be trimmed where necessary.

All wrought iron for pins shall be made of equal quality to the round bar iron required for this work, and shall stand the tests required for forged bars, as before specified. The pins shall be of the diameter shown upon the drawings, and shall be turned straight and smooth to gauge with bright surfaces, and coated for protection with white-lead before leaving the shops. The eyes to the bracing bars shall be forged out of the solid metal, and the pin holes shall be afterwards bored exactly upon the centre line of each member when placed in a position similar to that it is to occupy in the finished structure. A clearance of not more than one sixty-fourth of an inch is to be allowed between the diameter of the pin and the diameter of the hole into which it is placed, so that the pins may pass through the holes without driving. No scarfs or welds will be permitted through the length of any rod, or in any portion of the ironwork. Plugging also will be held to be sufficient cause for the rejection of any portion of the work.

The architects or their engineer reserve to themselves the power of making the tests upon any one piece of a finished portion of wrought-iron work delivered upon the site, a single piece to be cut out of any such finished portion for a test where selected by the architects or their engineer and afterwards made good by the contractor for the ironwork.

In punching plate, angle or other wrought iron, the diameter of the die shall in no case exceed the diameter of the punch by more than one-sixteenth of an inch. All rivet holes must be carefully and accurately punched or drilled, both as regards size and position, and be at right angles to the face of the plates or bars. They must be rimed out where necessary, so that when the several parts forming one member are assembled together, a rivet of one-sixteenth of an inch less in diameter than the hole can be entered hot into any hole, without reaming or straining the iron by drifts.

The rivet heads must be cup-headed, and of a uniform size, for the same diameter rivet throughout the work. They must be fully and neatly snapped, and concentric with the rivet holes. The rivets when fixed must completely fill the holes. Countersunk rivets must be flush at all bearings, the holes for the countersunk portion of the rivet being properly drilled to receive the sunk head.

All bolts in shear are to have a quarter-inch washer under the nut, so that the shearing strain may be taken by the body of the bolt. All bolts in tension are to be provided with a nut at each end. The screwed portion of round bars shall be of such a size that the diameter at the bottom of the thread shall be one-sixteenth of an inch in excess of the least or net diameter of the rod, the ends of the rods being jumped up so that their sections are not reduced when the threads are cut. The wrought-iron screw couplings shall be neatly forged and carefully bored and chased, care being taken that the right- and left-handed screws are cut upon the same centre line.

Wherever necessary for the protection of the threads during erection, precaution must be taken accordingly.

The cast iron is to be of the best quality of soft grey iron, and shall conform in thickness to that indicated upon the drawings.

All castings shall be perfectly sound, free from sand holes, air holes, or any other imperfections whatever, and shall be run from the cupola without any admixture of cinder.

All the surfaces, mouldings, and architectural ornament shall be smooth, clean, and sharp.

Any attempt to conceal defects in casting by the insertion of lead plugging or stopping of any nature whatsoever, shall be considered a sufficient reason for their rejection.

Three test bars shall, at the option of the engineer or the architects, be cast from each running of the metal, such test bars being 42 inches long, by 2 inches, by 1 inch. When cold, each bar shall be supported upon edges exactly 3 feet apart, and the bar being 2 inches deep and 1 inch wide, shall sustain a weight of 28 cwt. applied in the centre, with a deflection before fracture of not less than five-sixteenths of an inch. Careful records shall be made of the weight of each test bar. If the test bars taken from any running, do not stand the test required, all castings made from that running shall be rejected and broken up.

In casting the columns the centre line of the core must be perfectly straight throughout and concentric with the vertical axis of the column.

The bolt holes in the castings shall be cast accurately circular or drilled to a diameter which in either case shall not exceed one-twentieth larger than that of the bolt it is to receive. The joints in the columns are to be faced where indicated upon the drawings.

The joints in the cast-iron gutters are also to be faced and fixed to the satisfaction of the architects and their engineer.

All facilities for the inspection of the iron and workmanship by the architects and the engineer shall be furnished by the contractor. He shall supply without charge, when required, such samples as specified of the several kinds of iron employed by him in the construction. He shall bear all the expense of reasonable tests required by the architects, and must provide the means for so testing to the satisfaction of the engineer.

The workmanship throughout shall be first-rate in every detail. The architects and engineer shall have full power to reject any work which they may not consider to have answered the foregoing requirements, and such work must be immediately replaced by work of a satisfactory character at the cost of the contractor for the ironwork.

TABLE A.

Comparative Angles and Slopes of Roofs.

Proportions of rise to span.	Angle.	Slope.	Proportions of rise to span.	Angle.	Slope.
	° ′			° ′	
$\frac{1}{6}$	18 25	3 to 1	$\frac{2}{3}$	53 00	$\frac{3}{4}$ to 1
$\frac{1}{4}$	26 35	2 to 1	$\frac{3}{4}$	56 20	$\frac{2}{3}$ to 1
$\frac{1}{3}$	33 42	$1\frac{1}{2}$ to 1	1	63 30	$\frac{1}{2}$ to 1
$\frac{1}{2}$	45 00	1 to 1			

TABLE B.

Loads on Roofs exclusive of Framing, Snow and Wind.

Description of covering.	Weight in cwt. per square of 100 superficial feet measured on plan.	Minimum slope.
Zinc	$1\frac{1}{2}$	4°
Lead	7	4°
Corrugated iron	3	4°
Slates	$7\frac{1}{2}$ to 9	$25\frac{1}{2}$° to 30°
$\frac{3}{4}$" boarding	$2\frac{1}{2}$	25°
$1\frac{1}{2}$" boarding	5	—
Timber framing for slated roofs	5 to 6	—

TABLE C.

Thickness and Weight of Rough Plate Glass.

Thickness in inches.	Weight in ounces per foot super.	Thickness in inches.	Weight in ounces per foot super.
$\frac{1}{16}$	13	$\frac{1}{4}$	52
$\frac{1}{8}$	26	$\frac{5}{16}$	65
$\frac{3}{16}$	39	$\frac{3}{8}$	78

TABLE D.

Weight of Vieille Montagne Sheet Zinc per Square Foot.

Gauge.	Approximate weight per square foot.	32 × 84 inch.		36 × 84 inch.		36 × 96 inch.	
		Approximate weight of sheets.	Sheets per 500 kilos or 1102$\frac{3}{8}$ lb. Engl.	Approximate weight of sheets.	Sheets per 500 kilos or 1102$\frac{3}{8}$ lb. Engl.	Approximate weight of sheets.	Sheets per 500 kilos or 1102$\frac{3}{8}$ lb. Engl.
	lb. oz. drchm.	lb. oz. drchm.	about.	lb. oz. drchm.	about.	lb. oz. drchm.	about.
1	0 2 5	Sheets Nos. 1 and 2 are only rolled to order and special dimensions.					
2	0 3 4						
3	0 3 15	4 9 8	240	5 2 11	213		
4	0 4 13	5 9 13	196	6 5 1	175	7 3 8	153
5	0 5 11	6 10 3	166	7 7 7	147	8 8 8	129
6	0 6 11	7 12 13	141	8 12 7	126	10 0 8	110
7	0 7 12	9 0 11	122	10 2 12	108	11 10 0	95
8	0 8 14	10 5 11	106	11 10 6	95	13 5 0	83
9	0 10 5	12 0 8	92	13 8 9	81	15 7 8	71
10	0 11 7	13 5 8	83	15 0 3	73	17 2 8	64
11	0 13 5	15 8 8	71	17 7 9	63	19 15 8	55
12	0 15 2	17 10 5	63	19 13 10	56	22 11 0	49
13	1 0 15	19 12 3	56	22 3 11	50	25 6 8	43
14	1 2 12	21 14 0	50	24 9 12	45	28 2 0	39
15	1 5 12	25 6 0	44	28 8 12	39	32 10 0	34
16	1 8 12	28 14 0	38	32 7 12	34	37 2 0	30
17	1 11 11	32 4 13	34	36 5 7	30	41 8 8	27
18	1 14 11	35 12 14	31	40 4 7	27	46 0 8	24
19	2 1 11	39 4 13	28	44 3 7	25	50 8 8	22
20	2 4 10	42 11 11	26	48 1 12	23	54 15 0	20
21	2 8 12	47 8 11	23	53 7 12	21	61 2 0	18
22	2 12 14	52 5 11	21	58 14 6	19	67 5 0	16
23	3 1 1	57 3 13	19	64 6 5	17	73 9 8	15
24	3 5 3	62 0 13	18	69 12 15	16	79 12 8	14
25	3 9 5	66 13 14	17	75 3 9	15	85 15 8	13
26	3 13 7	71 10 13	15	80 10 3	14	92 2 8	12

Note.—*As it is impossible to roll sheets exactly to the given weight, a slight deviation from the above must be allowed.*

TABLE E.

Weight and Thickness of Sheet Lead.

Weight in lb. per superficial feet.	Thickness in inches.	Weight in lb. per superficial foot.	Thickness in inches.
1	0·017	7	0·118
2	0·034	8	0·135
3	0·051	9	0·152
4	0·068	10	0·169
5	0·085	11	0·186
6	0·101	12	0·203

TABLE F.

WEIGHT AND SIZES OF ROOF SLATES.

Names of Slates.	Sizes in inches.	Weight in cwt. per square of 100 superficial feet. First quality (Welsh).
Viscountesses	18 × 10	6
Countesses	20 × 10	5⅔
Marchionesses	22 × 12	6
Duchesses	24 × 12	6
Princesses	24 × 14	5½
Empresses	26 × 6	6⅓

TABLE G.

WEIGHT AND SIZES OF CORRUGATED IRON ROOFING.

Birmingham Wire-gauge.	Size of sheets in feet.	Weight per square of 100 superficial feet.
		cwt. qr. lb.
No. 16	6 × 2 to 8 × 3	3 0 14
No. 18	6 × 2 „ 8 × 3	2 1 6
No. 20	6 × 2 „ 8 × 3	1 3 6
No. 22	6 × 2 „ 7 × 2½	1 2 7
No. 24	6 × 2 „ 7 × 2½	1 0 24
No. 26	6 × 2 „ 7 × 2½	1 0 6

NOTE.—Add one-tenth of weight for lap of sheets, and allow 3 lb. of rivets per square of 100 superficial feet of roofing.

MIDLAND RAILWAY.—EXTENSION TO LONDON.

ST. PANCRAS STATION.—IRONWORK AND ROOFING CONTRACT, 1866.

Specification.

Extent of Contract.—The contract is to include supplying and erecting all the columns, and girders and plates forming the flooring of the station, and also the iron, timber work, glass and all other work of the roof, together with the ends thereof, and all other parts described or provided for in the drawings and specification, and maintaining the whole in perfect order and repair for twelve months after the whole is completed.

Requirements.—The contractor is to supply all labour, tools, materials, scaffolding, timbering requisite for the work whether temporary or permanent, including lighting and watching.

Compliance with Acts of Parliament.—He must comply with the Acts of Parliament of the Midland Railway Company, and all general or local Acts, and must be at all expense of giving notice to the local authorities.

Testing.—He must also provide for testing the several parts as hereinafter specified, and especially for the erecting and testing two of the main principles of the roof, which is to be done at the works where the same are constructed.

Works included in Contract.—In addition to the works shown upon the drawings, the contractor will have to make and erect the end framing at the south end of the shed which will be of similar character to that at the north end, but of less extent. The details of this will be supplied as the work proceeds.

Facilities to other Contractors.—The contractor is to conduct the work in such a manner as shall

not create any unnecessary delay or inconvenience to the contractors for the brickwork and masonry, and any stonework or other work damaged by the process of erecting the ironwork must be reinstated to the satisfaction of the engineer, and at the expense of the contractor for the ironwork.

Makers of Iron to be approved.—If the parties who contract for the erection of the roof are not themselves the makers of the iron, the name of the maker or makers (whether of the whole or any portion) shall be submitted to and approved by the engineer.

Sub-letting.—Neither the whole nor any part of the cast- or wrought-iron work included in the contract shall be under-let without the express written consent of the engineer and his special approval of the parties to whom it is proposed to intrust the work. If permission be given to under-let the ironwork, the sub-contractor shall be bound by indenture to the Company to observe and abide by all the terms and conditions of this specification as far as it may concern him.

Provisions for Models and Experiments.—In addition to the test specified, the contractor shall allow in his tender the sum of 500*l.* for models and experiments, and he will be paid so much of that sum as shall be certified by the engineer to have been expended.

Contract Drawings.—The works are to be executed in accordance with the contract drawings, subject to any modifications, whether of additions, deductions, or variations that the engineer may deem necessary.

Defective Materials and Workmanship.—The engineer shall have power to condemn and order the removal of all materials or workmanship which, in his opinion, are defective or unsound or unfit to be used; and all condemned materials not removed from the Company's premises within three days may be disposed of by the Company in such manner as the engineer shall think fit.

Plant and Materials.—As and where any plant or materials shall have been brought on to the site of the works or on the lands belonging to the Company, they shall immediately thereon become the property of the Company, and the contractor shall have no property therein, and no right to use the same except for the purposes of the contract and as the agent of the Company; but if the works be duly completed, then, after completion as a condition precedent, the Company shall give the said plant and surplus materials, if any, to the contractor, who shall remove them from the Company's premises within one month after the completion of the works.

Setting out Works.—The contractor shall provide at his own expense all posts, poles, and other materials which the engineer may consider necessary for setting out the work, and shall fix and maintain them in such positions as may be pointed out or as the nature of the work may render necessary, and shall allow in his tender a sum of 300*l.* for the same, provided that only so much shall be paid to the contractor as shall be certified by the engineer to have been expended.

Copies of Drawings.—The contractor shall at his own expense provide himself with copies of all such general drawings as may from time to time be supplied for his guidance; and shall further provide, in duplicate, at his own cost, such detail drawings as may be considered necessary by the engineer, who shall have the power to reject or alter them to any extent before giving his final sanction to them as working drawings; and no drawings so prepared shall be recognised as binding upon the Company unless approved and signed by their engineer for the time being.

Setting out Works.—The contractor shall at his own expense set out the whole of the works in accordance with the drawings from time to time supplied or approved by the engineer; and shall take upon himself all liability as to the correctness of the several lines and levels so set out by him, and shall at his own cost correct, reinstate, and make good any defects which may arise from errors in such setting out or levels.

Quantities.—The contractor shall from time to time and at all times provide at his own cost all reasonable labour and assistance, and shall give all such facilities and information as the engineer may require for the purpose of ascertaining the quantities of work completed or of materials supplied towards the execution of the contract.

Contractor liable for certain Claims.—The contractor will be held responsible for all claims brought against the Company on account of the interruption of or damage done to any of the public or private highways or roads, or on account of any damage sustained by any party or parties in

consequence of interruption of such highways or roads, or on account of damage done through insufficient fences or hoards, or through trespass upon any of the properties adjoining the intended works, or through trespass on the Company's property, or on account of any gas or water pipes, drains, sewers, or water-course which may have been interfered with, or in any way injured during the progress of the works, or on account of any damage sustained in consequence of such interference or injury if occasioned by the contractor.

Claims to be settled within one Month.—All reasonable claims brought against the Company for damage done by trespass or otherwise, if not satisfied by the contractor within one month after presentation, shall be paid by the Company and the amount deducted from any money that may then be due, or which may afterwards become due to the contractor.

Power to dismiss Men.—The engineer shall have power, without notice, to dismiss any man or men whom he may deem unfit for the duties assigned him or them; and to employ at the contractor's expense any other in their places, and all such as have been so dismissed will be held as trespassers if they continue on the works, and will be proceeded against accordingly.

Royalties and Patent Rights.—The contractor is to hold the Company harmless against all claims for royalties or charges for or in respect of patent rights for any articles used in the works executed under this contract.

As to Differences between the Contractor and the Company.—In the event of any difference arising between the Company and the contractor as to the terms of the contract or as to the true intent and meaning of this specification, or as to any matter or thing arising therefrom, excepting always to quality of materials and workmanship and the mode of conducting the work (in which case the decision of the Company's engineer for the time being shall be final and binding on all parties), power shall be reserved to either party to refer such question or difference to arbitration in the usual manner.

Returns.—The contractor shall make a correct return every month, or oftener if required, of the number of men employed by him on every portion of the work, distinguishing between the different classes of workmen, according to a form to be supplied to him, and shall, as often as required, supply any other information relative to the construction and progress of the works.

Net Measurements.—Notwithstanding any custom to the contrary, net measurements only will be allowed and paid for upon all works executed and materials delivered in accordance with the terms of the contract and specification, and all prices given in the Schedule attached hereto shall include labour and materials unless otherwise specified in the case of any particular item.

Quantities.—The contract quantities are only approximate; any difference between them and the total quantities of work executed must be paid for or deducted according to the Schedule of Prices, except where otherwise expressly stipulated and provided for.

Quantities.—The contractor will be required to pay one per cent. for taking out the quantities and measuring up the works when completed. Of this sum 300*l.* must be paid on taking the contract, and the remainder shall be paid from time to time as it becomes due upon the certificates or payments made to the contractor.

Adjustment of Prices.—The Schedule of Prices shall be examined previous to the signing of the contract, in order to ascertain that the quantities moneyed out at the prices stated therein amount to the sum stated in the tender; and if not, the prices must be adjusted until the quantities so moneyed out agree with the sum set forth in the tender.

Unspecified Work.—For additional work, if any, for which no provision is made in the Schedule of Prices, the engineer and contractor must endeavour to agree and fix a price; but in case they cannot agree, the engineer shall be at liberty to employ any other person or persons to do the required work.

Drawings.—In the event of any discrepancy between the drawings and figures written upon them, the figures are to be taken as correct; and in case of any discrepancy between the drawings and specification, the specification is to be adhered to; and if any question arise thereon the decision of the engineer shall be final and binding.

Prices.—The sums stated in the Schedule of Prices are to cover the whole of the requirements of this specification, and all contingencies or other works incidental thereto.

Periodical Accounts.—The contractor must send in an accounnt every month of the work performed during the month; and no claim for any extra or additional work shall be allowed unless such claim be made within one month from the commencement thereof.

No daywork shall be allowed or paid for unless the same shall have been done in compliance with a written order from the engineer; and for all daywork so done, the contractor shall send in a weekly return, stating the names of the men, and the work performed by them; and no claim whatever will be allowed for daywork unless a return, as above described, is sent in within fourteen days of such work being done.

Monthly Payments.—The contractor will be paid upon monthly certificates signed by the chief engineer, upon the work actually executed, deducting therefrom 10 per cent., which will be retained by the Midland Railway Company until the final completion of the contract.

Six months after the works shall have been certified by the engineer, as being complete, the contractor will be entitled to receive the retention money, and twelve months after the completion of the works, he shall be entitled to receive the remainder, provided that the works have been duly maintained.

Interest.—The contractor shall not be entitled to interest upon any of the moneys retained under the terms of this contract, nor upon the balance which may on the final settlement of his account be found to be due to him.

Additional Work.—The contractor must allow in his tender a sum of 5000*l.* to cover the cost of any additional work which may be ordered by the engineer, which additional work, if ordered, will be paid for according to the Schedule of Prices.

Quality of Wrought Iron.—The wrought iron used throughout the work, except the flooring plates, rivets, and small ironwork, shall be Yorkshire or Derbyshire iron, of such quality that an inch bar will bear a tensile strain of not less than 22 tons before fracture, and a strain of 11 tons without any permanent set. The flooring plates may be of Staffordshire iron of approved quality, capable of bearing 20 tons per inch before fracture, and 10 tons without permanent set. The rivets, bolts, and nuts, and small pieces of iron under 1 lb. in weight, must be of or equal to the best S. C. crown iron.

Girders.—The main floor girders must be capable of bearing as detached girders a weight of 60 tons, evenly distributed over a bearing of 14 feet 8 inches, with a deflection not exceeding one-fifth inch, and the intermediate floor girders must be capable as detached girders of bearing a weight of 50 tons distributed over the same bearing with the same deflection.

The cross girders must be capable of bearing a weight of 18 tons evenly distributed with a bearing of 14 feet between the supports with a deflection not exceeding one-fifth inch.

Testing.—The engineer may select one out of every 4 girders to test as described, and should they be unable to bear the test, the contractor must be at the expense of testing the whole of the remainder of the girders, and must replace with good and sufficient girders any which may be found unable to bear the test, or be otherwise defective.

Additional Testing.—If in the erection of any part of the work there is any reason to doubt the quality of the materials or workmanship, then it shall be submitted to such tests as the engineer may think necessary at the sole risk and cost of the contractor, and he shall replace with good and sufficient materials and workmanship any parts which may be found defective.

Preparation of Ironwork.—The ironwork of the girders, angle irons and plates of the flooring and of all other parts where required, must before leaving the works be submerged in coal tar, or otherwise coated therewith when the iron is heated to about 700° Fahr.; and must receive a second coat of tar when erected.

Testing Roof.—Two main principals of the roof shall be erected at the works, upon proper abutments, erected for the purpose, and connected at the feet by the girders which will be used for that purpose under the flooring. The principals shall be erected with purlins complete in every respect, and shall be tested in the presence of the engineer, or an assistant appointed by him. First a weight of 200 tons or 100 tons on each principal shall be evenly distributed. Next, 25 tons shall be taken from one side of each principal, leaving 50 tons upon the other side, and making the relative loads 25 tons and 50 tons on the two sides of each principal.

Workmanship.—The edges and ends of every plate or other piece of iron forming butt joints shall be planed to perfectly true lines, so that the plates or abutting parts may touch each other throughout the entire length of every butt joint, and so that the rivet holes may, if required, be punched or drilled correctly by measurement from the edges only. Great care should be taken in the riveting of such butt joints that the perfect contact of these surfaces may be maintained, the edges of all the plates in the roof ribs shall be planed to equal widths, so as to form true and even lines.

Girders, &c., to be built with Camber.—All girders, beams, and joists shall be built with a camber on the underside as may be directed.

Riveting.—All rivet holes shall be drilled. Every precaution shall be adopted to secure the precise correspondence of all the holes through any number of plates or bars, and the exact fitting of the rivets within such holes; and when necessary to test the workmanship in this respect rivets shall be cut out wherever directed.

Bar, L, T, and [Iron.—All bar, angle, tee, and channel iron shall be of the exact section shown upon the drawings, and any that may be cracked or split at whatever stage of the work it may be discovered, will be rejected, and shall be removed and replaced by other iron of better quality and workmanship. When required to be cranked or bent for knees, laps, or otherwise, it shall be done with the greatest care, and with easy curves, and without any abrupt bend or square shoulder.

Cast Iron.—All cast iron used upon the contract shall be clean, sound castings, entirely free from sand, air holes, or other defects, and shall be run from the cupola without any admixture of cinder.

Test Bars.—The contractor shall cast at every melting at least 3 test bars, 2 inches deep by 1 inch thick and 5 feet long, which bars when cold shall be broken under a dead weight at the centre, upon a 4 feet 6 inch bearing. Careful records shall be kept of the breaking weight of each bar, and should they average on each lot of 3 bars less than 1800 lb., the engineer shall be at liberty (should he think fit) to reject all and any of the castings run from that particular melting to which the defective bars belong.

Joints in Cast-iron Work.—All the joints in the cast-iron work shall be provided with proper chipping pieces, and shall be accurately fitted together. The bearing surfaces shall be made perfectly true by planing, chipping, filing, or otherwise; and all bolt holes shall be rimed out to the exact diameter required to receive the bolts.

No Casting to be painted until approved.—No casting shall be painted until it has been examined and approved by the engineer or his inspector, after which it shall be thoroughly scraped, cleaned, and well painted as hereinafter described.

Defects in Castings.—All castings in which any plugging or other attempt to conceal any apparent defects may be discovered will be rejected, whether they have previously borne the required test or not.

Measurement and Weight of Ironwork.—The average weight of ironwork in any case where it cannot be ascertained by actual weighing, shall be taken at 480 lb. per cubic foot for wrought iron, and 450 lb. per cubic foot for cast iron. If in any case the weights are less by 2 per cent. than the measured quantity according to the drawings, the work will be rejected, and if in any case the weight exceed that estimated by measurement of the drawings by more than 2 per cent., the excess over the 2 per cent. will not be paid for by the Company.

Timberwork.—The whole of the timber shall be of Memel, Riga, or Dantzic red pine, except the planks, deals, and battens, which shall be of the best yellow deals of Christiania or Petersburg.

All the timber must be well seasoned, thoroughly sound, straight, free from sap, shakes, dead knots, and other defects.

Prices for Timberwork to include all nails, screws, spikes, &c.—The average prices of the timberwork shall include the cost of all nails, screws, spikes, and other light ironwork, or other work or materials necessary for the proper connection of the several parts and Burnettizing where described on the drawings.

Painting, Varnishing, and Burnettizing.—The whole of the timberwork, with the exception of

the gangway and gutter boarding and the boarding under slates, to be knotted, stopped, and primed before erection, and to have three coats of best oil paint after it is fixed complete, and the last two coats to be of such colour as may be directed.

The gangway and gutter boarding must be Burnettized in the most approved manner.

Varnishing Boarding.—The whole of the underside of boarding to roof to be stained and varnished with two coats of the best copal varnish.

Painting Ironwork of Roof.—The wrought-iron work of the roof to have one coat of the best "iron minium" paint, after all the rust or oxide is removed before the work is put together, and another coat of the same paint to be put on as soon as the work is riveted together, and to have two more coats of the same paint after the ironwork is completely erected and fixed, the colours and quality used to be approved by the engineer.

Lead-work.—The several flashings and coverings to roof, as shown in drawings, to be 7 lb. milled lead laid as shown, and well dressed down close round all projections.

All joints in the lead-work to be made with rolls, laid free and so as to allow of expansion and contraction.

Slating.—The slating of roof to be of the best Welsh slates, one-fourth of the slating of the roof to be of Duchess slates, one-fourth of Countess, one-fourth of Ladies, and one-fourth of Doubles; the Duchess slating to commence at the eaves, and the courses to diminish towards the skylights. Each slate to be securely fastened to the slate boarding with two copper nails weighing not less than 7 lb. per thousand. The lap of the slates to be in no case less than 3 inches.

Glazing to Skylights.—The glass to skylights of roof and the gables to be patent rough plate-glass $\frac{3}{16}$ of an inch thick, well bedded and puttied with putty of the best quality, containing a sufficient proportion of Russian tallow and putty. Each square of glass to be sprigged and secured with metal clips, as shown on drawings, and the whole to be left clean and perfect.

Galvanized Iron.—The covers of the ventilators are to be made of galvanized iron.

The quality shall be that known as the best charcoal iron, and galvanized or coated with zinc in the best and most approved manner. The galvanized iron is to receive three coats of the best "zinc minium" paint, to be put on as and when directed by the engineer.

Delivery of Girders and Columns.—The delivery and erection of the columns and girders is to commence on 1st September next, and to continue at the rate of 30 columns, with their cross-girders and plates, per week. The work is to commence at the south end of the station, and to proceed evenly towards the northern extremity.

Delivery of Principals of Roof.—The first principal of the roof is to be delivered and erected by November 1st, 1866, and the work is to continue at the rate of one principal with all other work necessary to complete one bay per week until the whole is complete.

Completion of the Works.—The whole work is to be delivered up complete, including the gables, and all scaffolding cleared away by August 1st, 1867.

Southernmost Principal to be erected first.—The southernmost principal is to be erected first, and the work is to proceed regularly towards the northern end.

Provision for working Traffic.—The timber framing employed in erecting this station shall be such as to permit trains of passenger carriages to pass under it, so that the southern extremity of the station may be used for traffic as soon as one half is completed.

NOTE.—*For the Diagram of Strains in the main principal of the St. Pancras Station roof* *see page* 52, *and for explanation see pages* 57 *to* 63. *For a comparison of the vertical area of this roof with other roofs* *see Plate* 70.

FORM OF AGREEMENT FOR THE ERECTION OF A STRUCTURE.

An Agreement made the day of one thousand eight hundred and **Between** hereinafter called "the said Contractor," of the one part, and of the other part, **Whereby** the said Contractor doth, for himself, his heirs, executors, and administrators, contract and covenant with the said that he, the said Contractor, will, in a good substantial and workmanlike manner, and with materials sufficient and proper of their several kinds, execute, perform, and so complete all and singular the work mentioned in the specifications and general conditions now produced and signed by the said Contractor, or thereby or by this contract implied, or to be reasonably inferred in and about the erection of upon the of the said at according to the said specifications and general conditions, and to the plans and drawings prepared by the Architect of the said works, and now produced and signed by the said Contractor, and according to such working and explanatory drawings and instructions as may from time to time be furnished by the said Architect, the said work to be begun, proceeded with, and completed to the satisfaction of the said Architect, to be testified by a writing or certificate under his hand. **And also** will find and provide all tools, tackle, and implements which may be required for the execution of the said work. **And it is hereby agreed** by and between the said parties hereto that, in case any of the materials used, prepared, or intended to be used by the said Contractor, shall, at any time, be considered by the said Architect or by the Clerk of Works to be appointed by him, as unsound or improper, the said Contractor will, at the request of the said Architect, or Clerk of the Works, reject and remove the same from the said premises. **And**, that in default of such rejection and removal within three days after such request, it shall be lawful for the said Architect or Clerk of Works to cause the same to be removed at the expense and risk of the said Contractor (such expense, if not defrayed by him, to be deducted out of the next payment due to him) to such place as the said Architect or Clerk of Works may think proper. **And**, that in case the said Architect or Clerk of Works shall consider any part of the work unsound or improperly executed, or otherwise deficient, the said Contractor, on notice given by the said Architect or Clerk of Works, shall cause such work to be immediately removed and properly re-executed without any extra charge whatever. **And** if the said Contractor shall neglect to remove anp re-execute such work, it shall be lawful for the said Architect or Clerk of Works to cause the same to be removed and re-executed at the expense of the said Contractor (such expense, if not previously paid by him, to be deducted out of the next payment which may be due to him). **And** if the said shall think proper at any time, before the said works are completed, to make any alterations, additions, or omissions to, in, or from the same; and the said Architect shall give written instructions, signed by him, to the said Contractor for such alterations, additions, or omissions, then, but not otherwise, the same shall be done or made by the said Contractor, and any alterations, additions, or omissions, if the price be not stipulated in the said specifications, shall be measured or estimated and valued by the said Architect, and the amount thereof, according to the price or value, shall be paid for unto, or be rebated and allowed for by the said Contractor, and the certificate of the said Architect shall be final as to all such alterations, additions, or omissions. **And** that all daywork done, and all materials supplied for daywork, shall be valued by the Architect, who shall give his certificate in respect thereof, which certificate shall be final and binding on the said parties hereto. **And** that the Architect shall have absolute control over all works executed upon or about the site and premises, whether such works shall be comprised in the original plans and specifications or not. **And** that any loss or damage which may happen to the said works, or the materials or implements therein used during the progress of the said works, which shall arise from theft, spoiling, decay, waste, wind, rain or fire, shall be effectually made good by the said Contractor at his own expense; and that during inclement weather the said Contractor, if and while he shall be thereto required by the said Architect or Clerk of Works, will suspend the performance of the said works. **And** that in caso the said Architect shall be dissatisfied with any foreman or workman who shall be employed by the said Contractor in the performance of the said works, and shall give notice in writing to him thereof, the said Contractor will within forty-eight hours next following discharge from the works aforesaid such foreman or workman; and if the said Contractor shall neglect so to do, it shall be lawful for the said Architect to discharge such foreman or workman, and to hire and employ any other person in his stead at the expense of the said Contractor, such expense, if not previously paid by to be deducted out of the next payment due to the said Contractor, and that the said Contractor shall not nor will sublet the execution of the said works or any part thereof. **And** the said doth hereby for himself, his heirs, executors and administrators, **agree that** he the said will well and truly pay or cause to be paid unto the said Contractor, his executors or administrators, the sum of in manner following, that is to say

tho sum of eighty pounds per centum upon tho valuo of tho works dono and materials npon the said promises, such percentage to bo ascertainod by tho said Architect and certified in writing nnder his hand, to the said

and tho balanco of tho said sum of

together with or less by tho amount of tho altorations, additions, or omissions made by order of tho said Architect within two calendar months from tho timo whon tho full and satisfactory completion of this contract shall bo certified to tho said

by tho said Architect. **Provided always and it is hereby agreed and declared** by and between the said parties hereto, that if at any time aftor tho works heroby contracted to bo performod shall havo boon certified by the said Architect to have been completed to his satisfaction and either beforo or aftor tho said Contractor shall havo receivod from tho said

any payment on account thereof, it shall appear that tho said Contractor hath not performed tho said work according to the torms of this contract, it shall bo lawful for tho said

to institute any action or suit against the said Contractor for tho damages sustained by him in consequence of such non-performance, and tho said certificate shall not bo pleadable in bar thoreto, nevertholess tho decision of tho said Architect with respect to the value or amount of the works executed or omittod, and every question that may arise concerning the construction of these presents and of the said specification, or of any mattor or thing relating thereto, shall bo final and conclusivo. **And** if the said Contractor shall, from bankruptcy, insolvency, or any causo whatever, be proventod or delayed in proceeding with the said works, according to these presents, or shall not procced thoroin to tho satisfaction of tho said Architect, it shall be lawful for the said

after seven days' previous notice, signed by him, his oxecntors or administrators, or by the said Architect, to be left or given in manner hereinaftor mentioned, of his intention so to do to employ any other workman, or other person, by contract, measure and value, daywork, or otherwise, to proceed with tho said works and to completo the same, and on tho expiration of the said notice, these presents shall, at the option of the said

become void as to tho said Contractor, but without prejudico to any right of action in tho said premises which the said Contractor may bo subject unto for any voluntary neglect in not proceeding with tho said works pursuant to this present contract, and the amount thon already paid to the said Contractor by the said

shall bo considered to be the full valuo of tho works oxecnted by him up to the timo when such notice shall have expired, and no further claim whatevor shall bo mado by tho said Contractor nnder these presents for contract works or additional works which may bo dono by him up to that time, and the materials, whether propared or unprepared, which may be at that timo on the premises, shall become the property of tho said

without further payment for tho same, and tho said Contractor shall not in any manner provent, hinder, or molest the said

or the persons employed by him in proceeding with and completing tho said works, and using such materials as aforesaid. **And**, that if any dispute shall arise between the said partios hereto touching or concerning the works hereby contracted to be done, or any altered, additional or omitted work, or in any wiso relating theroto, such disputo or differenco shall, whether this contract shall have been determined or not, be referred to the said Architect of the said works, whoso decision shall be final and binding on all parties. **And**, that in case of the death of the said Contractor beforo the matters herein undertaken by him shall be fully performed, his executors or administrators shall perform the samo, and shall be nnderstood and deemed to be in his stead. **And** that the giving to or leaving at the usnal or last place of abodo of tho said Contractor, his executors or administrators, or tho giving to his or their foreman or superintondent of tho works, of any notices, instructions, or drawings to be given or furnished under this contract, shall be doemed good servico or delivery thereof to tho said Contractor, his executors or administrators. **And** that if tho soveral portions of the said works shall not bo respectively finished and completed on or beforo tho respectivo times following, that is to say

and if the whole of tho said works bo not finished and completed on or before tho day of next, the said Contractor shall forfeit and pay to tho said

the sum of for each and overy wook beyond oither of tho said last-mentioned periods that snch respectivo works shall bo and continuo unfinished as liquidatcd damages to bo recovered in any Division of tho High Conrt of Justice, or in any County Conrt, otherwiso to bo deducted ont of any sum that may ultimately be or become duo to the said Contractor, in respect of this contract. **And it is hereby further agreed** that seven days will be allowed from the date hereof, in order that tho Contractor may examino the plans and specifications to test tho accuracy of tho list of qnantities, and any errors discoverod thorein and communicated in writing to tho Architect within that timo will be rectified, and be added to or deducted from tho amount of the contract price as tho case may be, but no additions or deductions will be mado in respect of such errors after tho expiration of tho said seven days; snch additions or dednctions to be mado by tho Architect, whose decision shall bo final.

As witness tho hands of tho parties hereto,

. WITNESS,

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„ Table of Weights, 79

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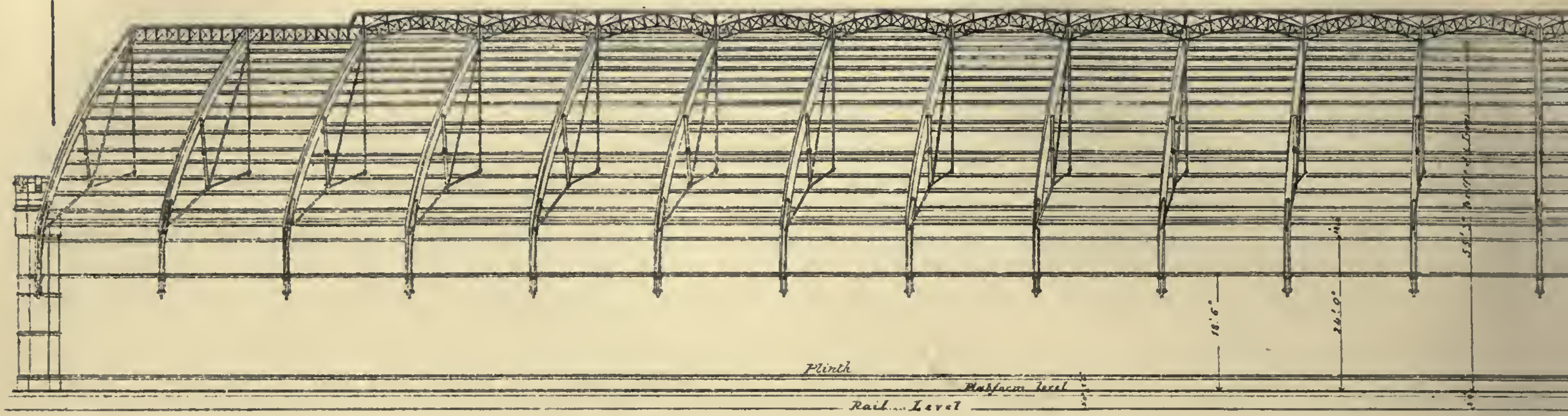
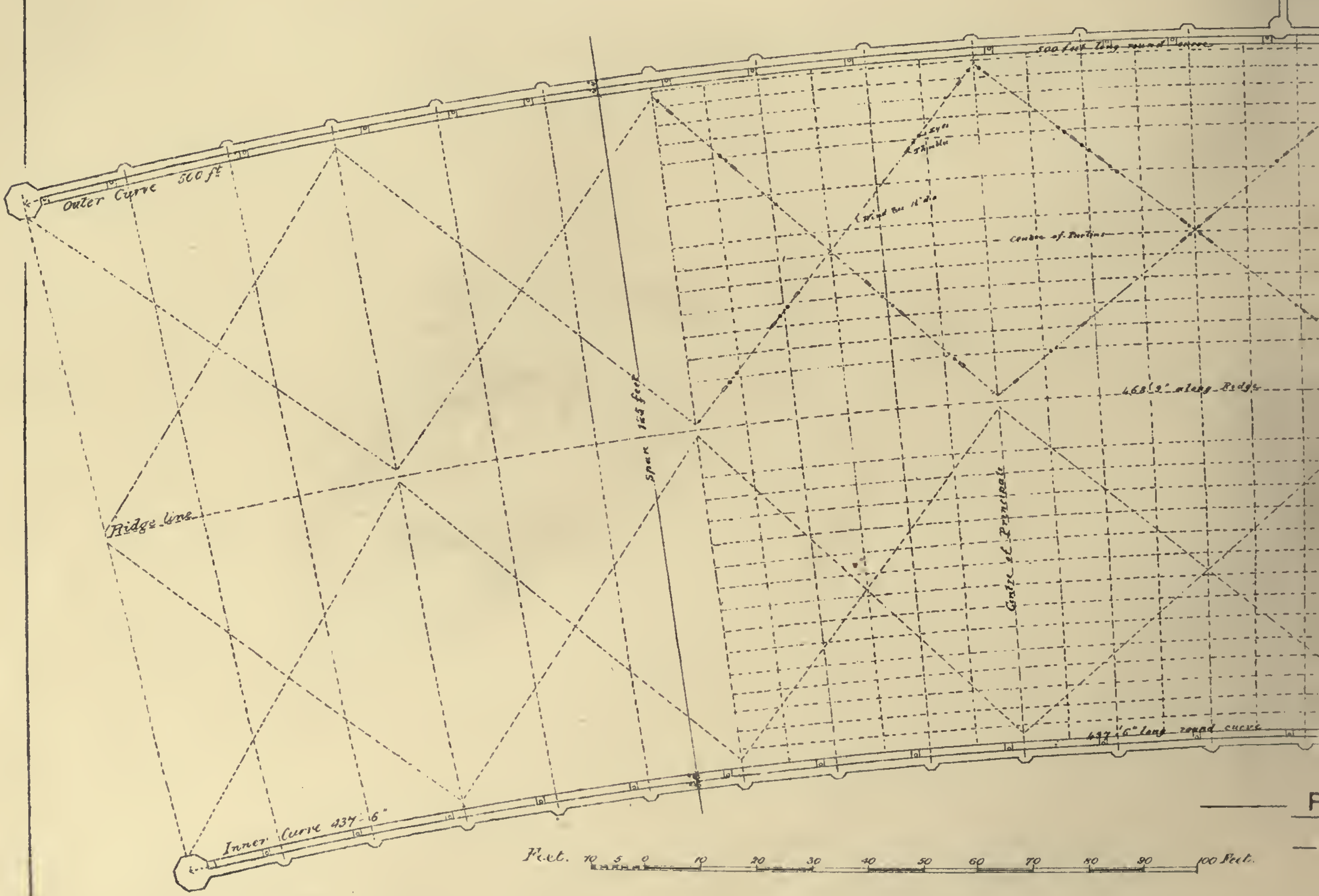
BRISTOL JUNCTION STATION

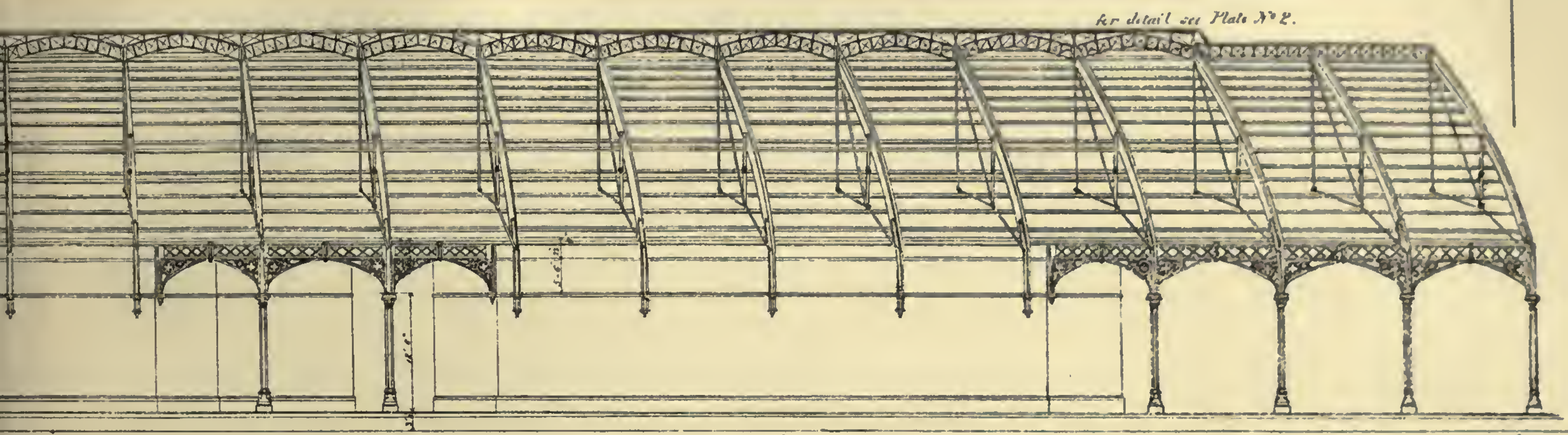


LONGITUDINAL SEC



F

MAIN SHED ROOF



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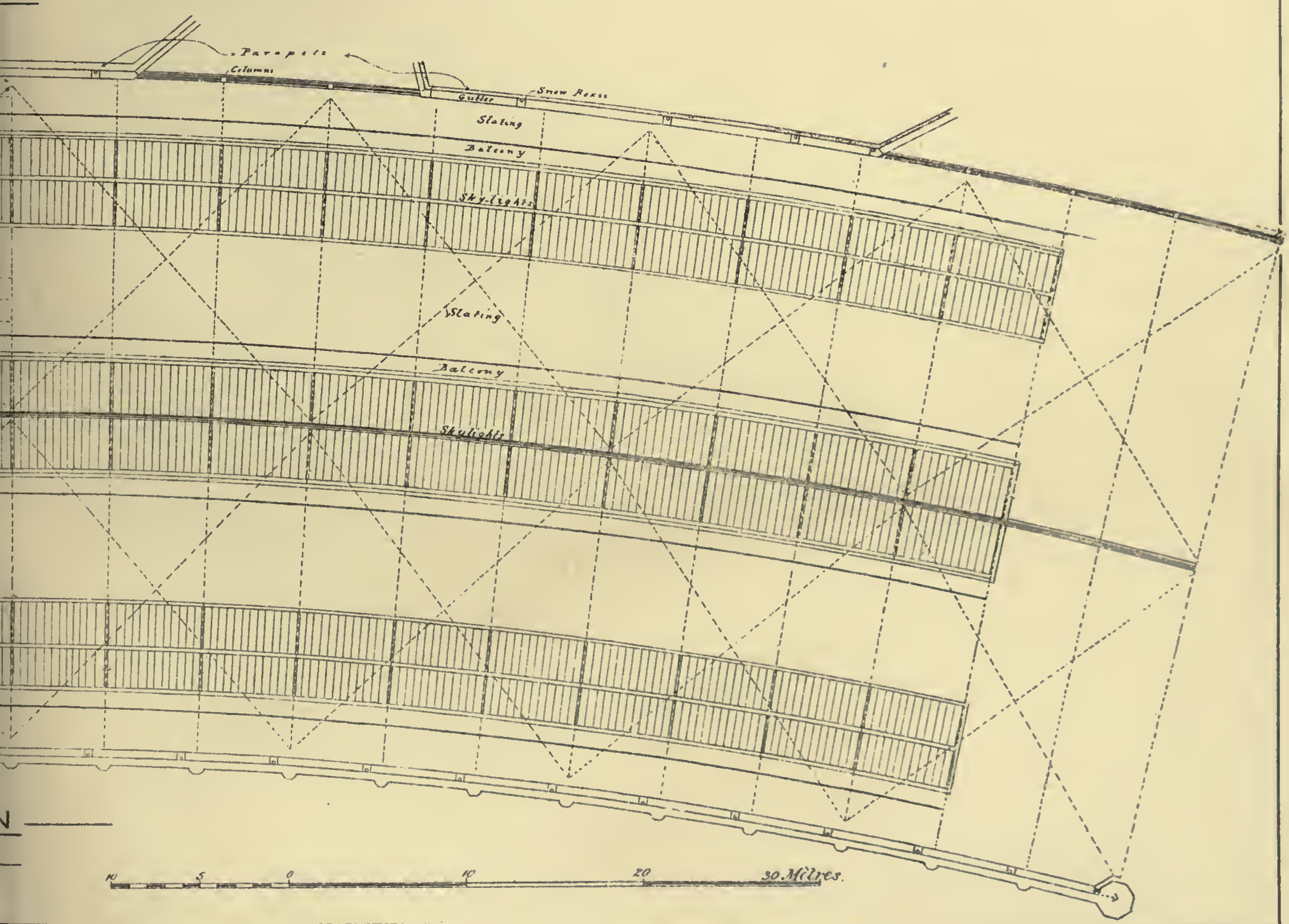

N

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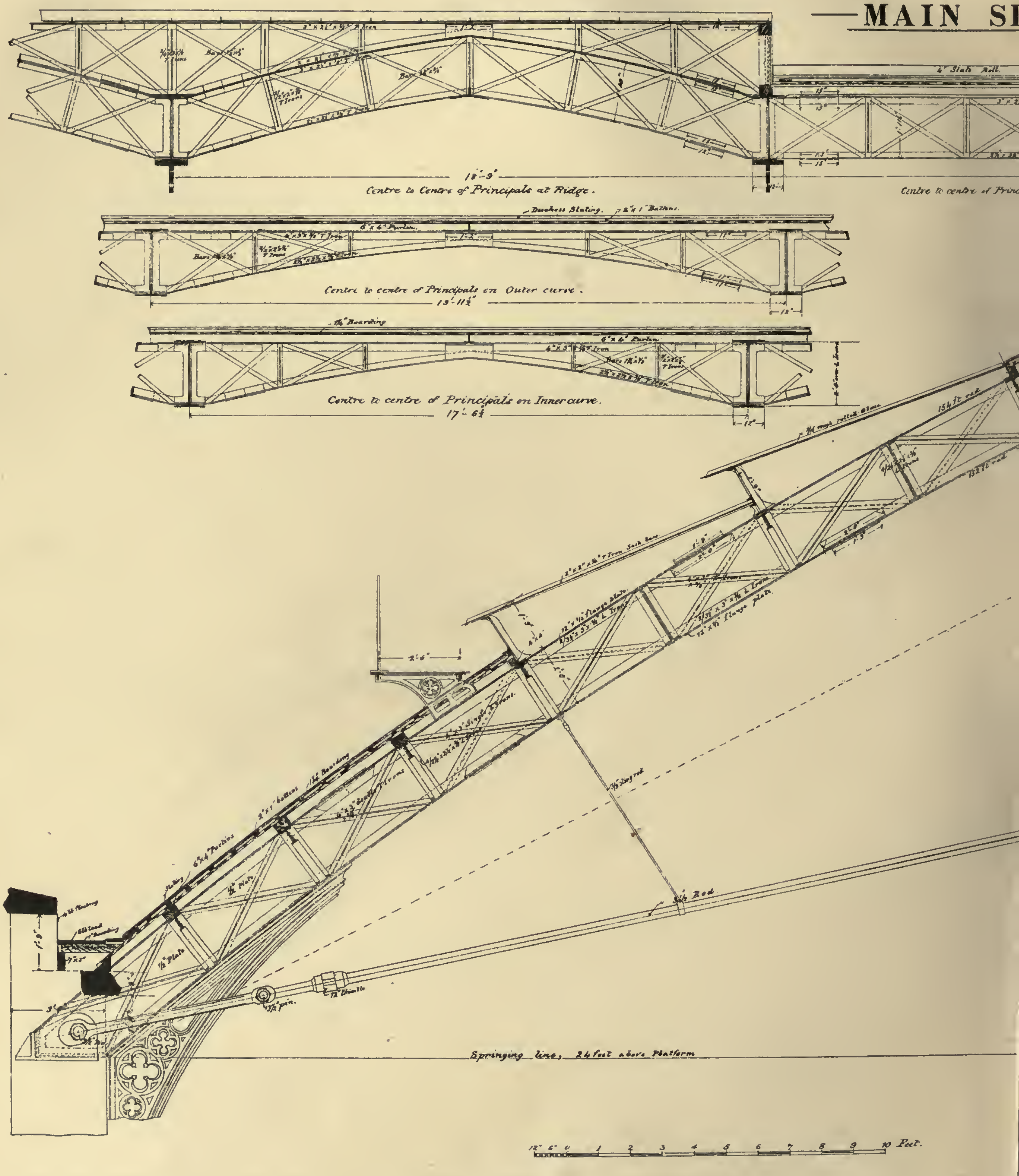
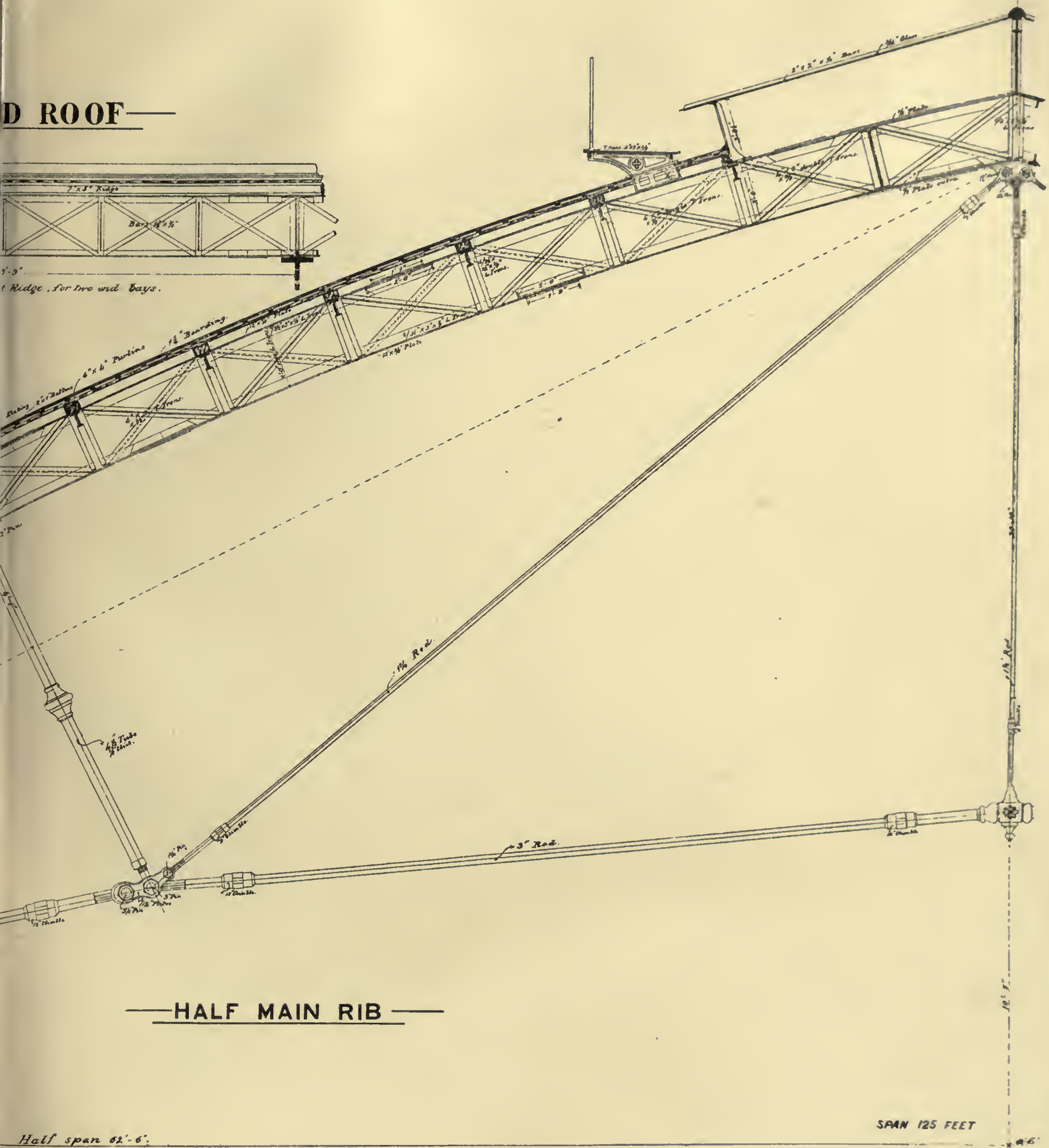
BRISTOL JUNCTION STATION

MAIN SH...



D ROOF—



—HALF MAIN RIB—

E.

10 5 0 1 2 3 Mètres.

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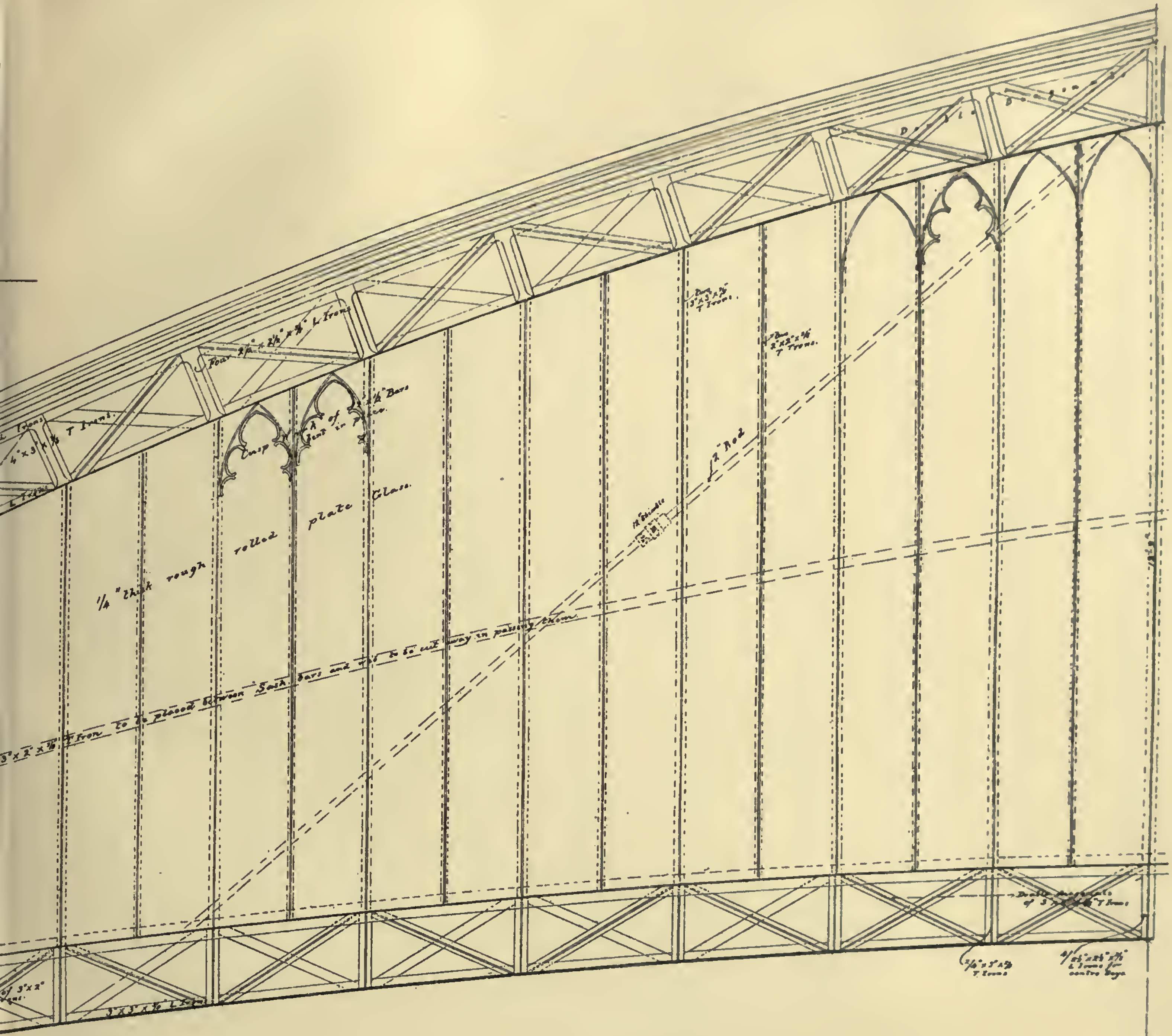
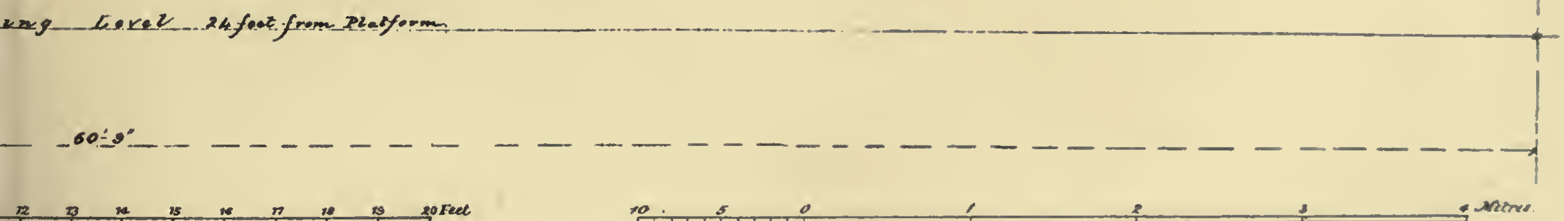
—BRISTOL JUNCTION STATION—

—MAIN SHED ROOF



VATION OF CABLE



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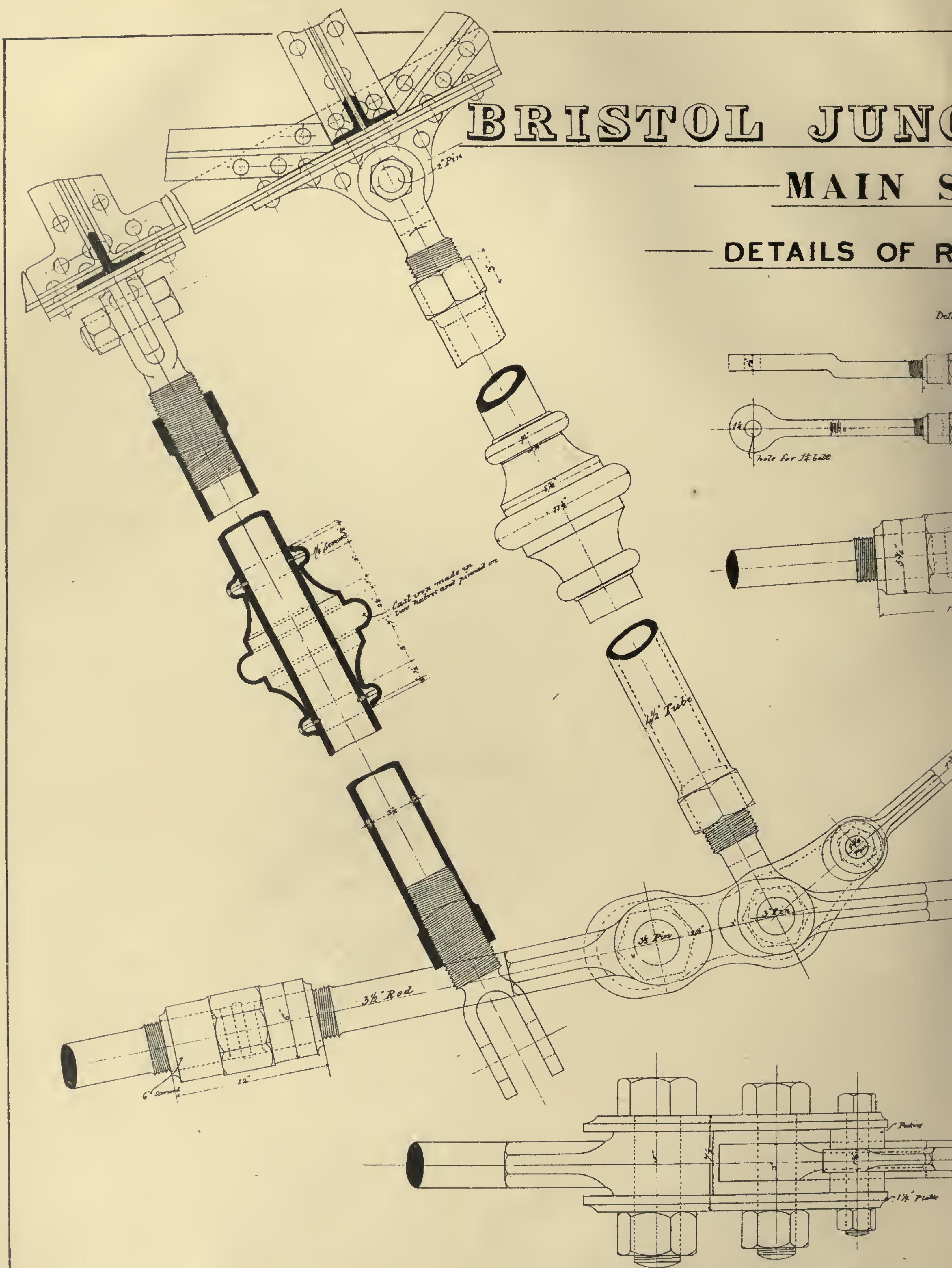
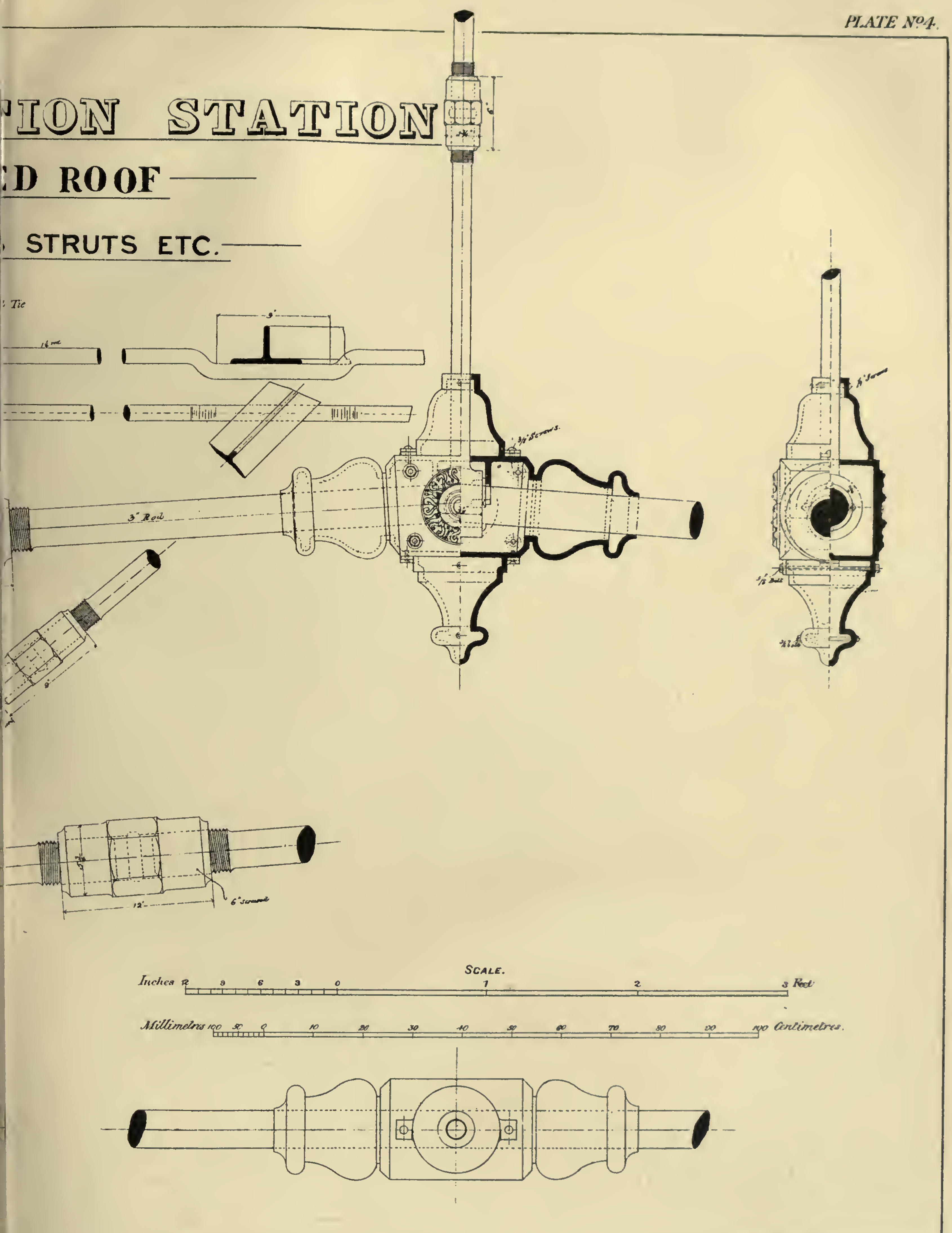

BRISTOL JUNC
MAIN S
DETAILS OF R
2" Pin
Cast iron made in two halves and pinned on
1¼ Screws
4½" Tube
3½" Rod
12"
6" Screwed
3½ Pin
3" Pin
hole for 1¼ bolt
Packing
1¼" Plates

TION STATION

ED ROOF

STRUTS ETC.



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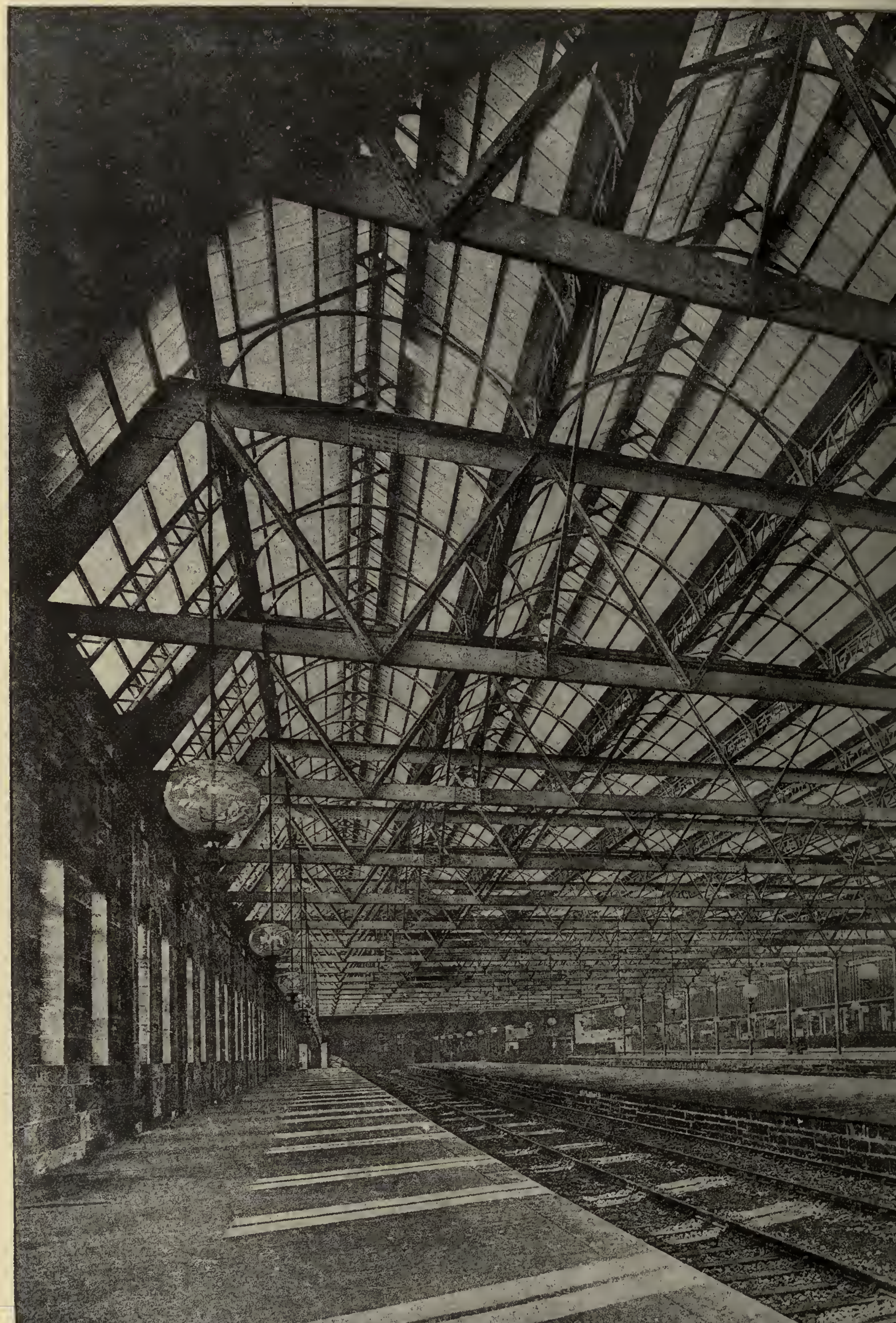

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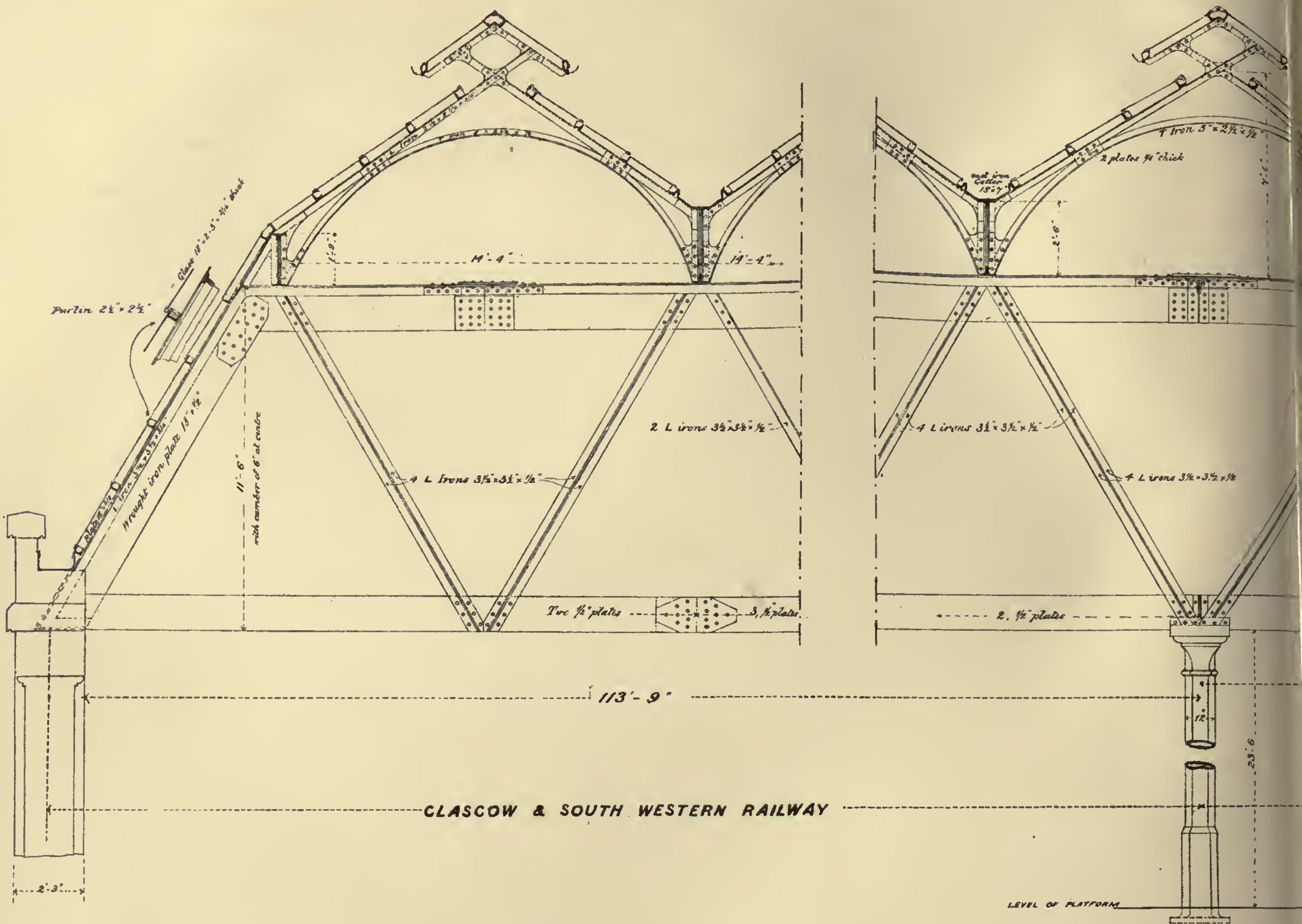
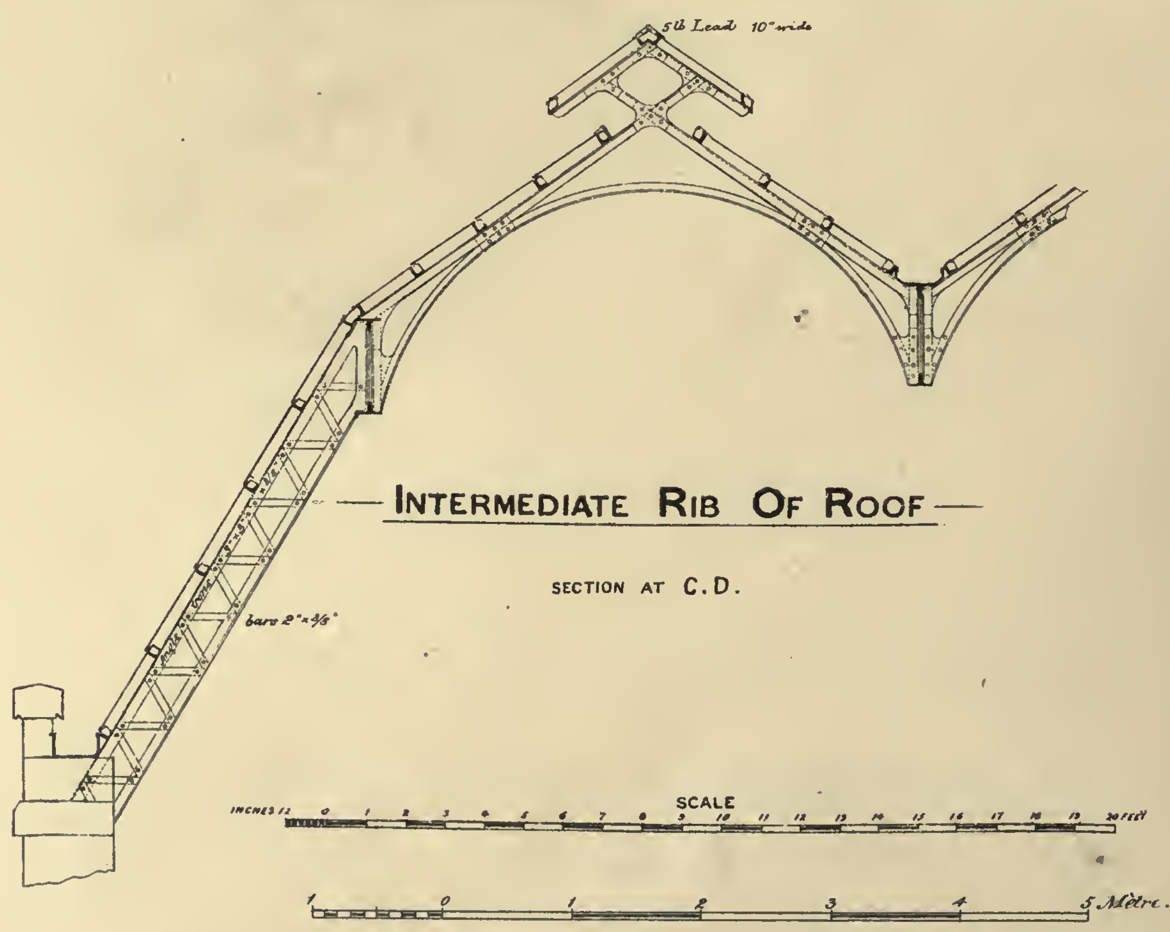
BRIDGE STREET

TION . GLASGOW .

BRIDGE STREET STATION. GL



TRANSVERSE SECTION.

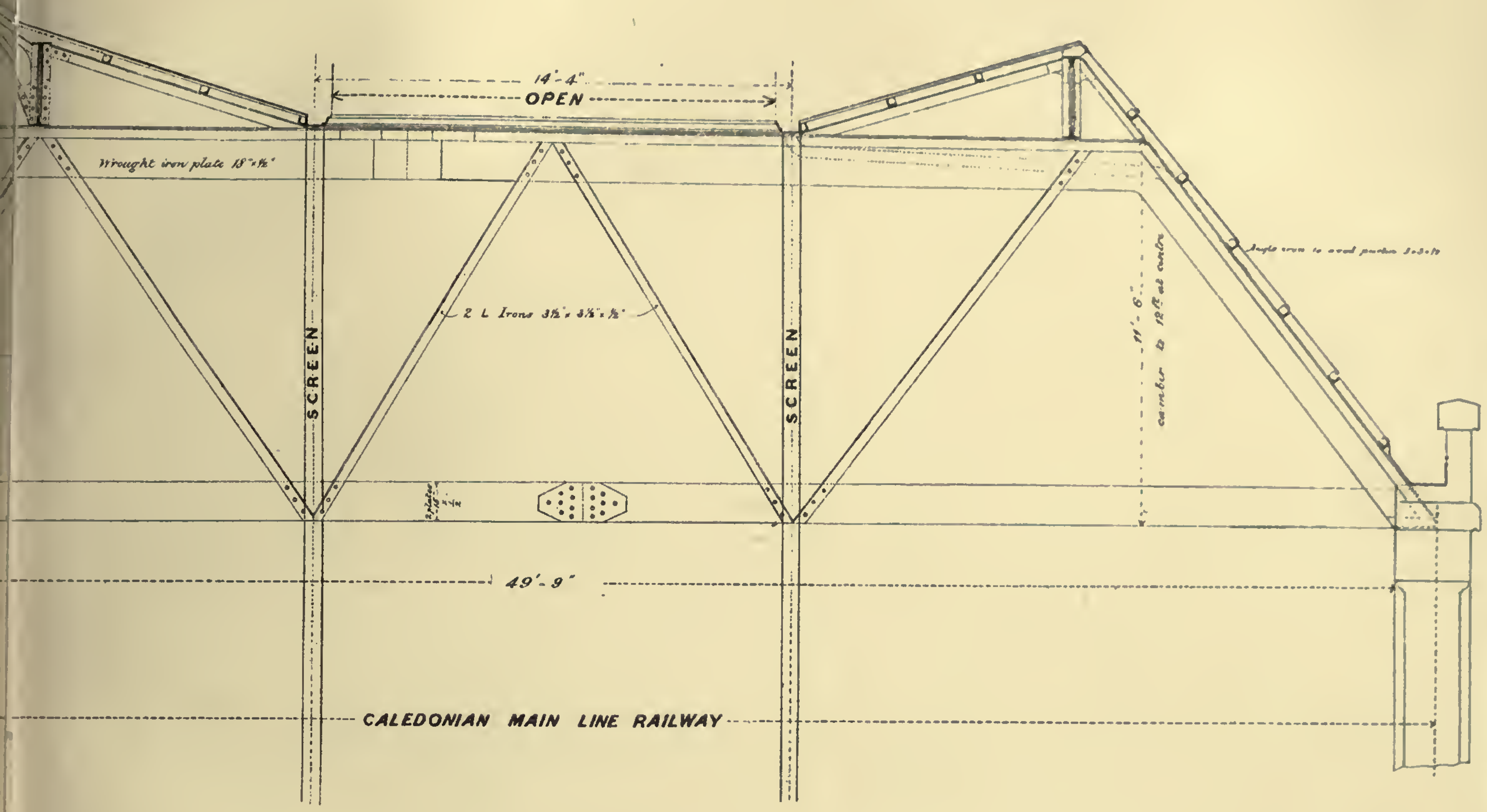


INTERMEDIATE RIB OF ROOF

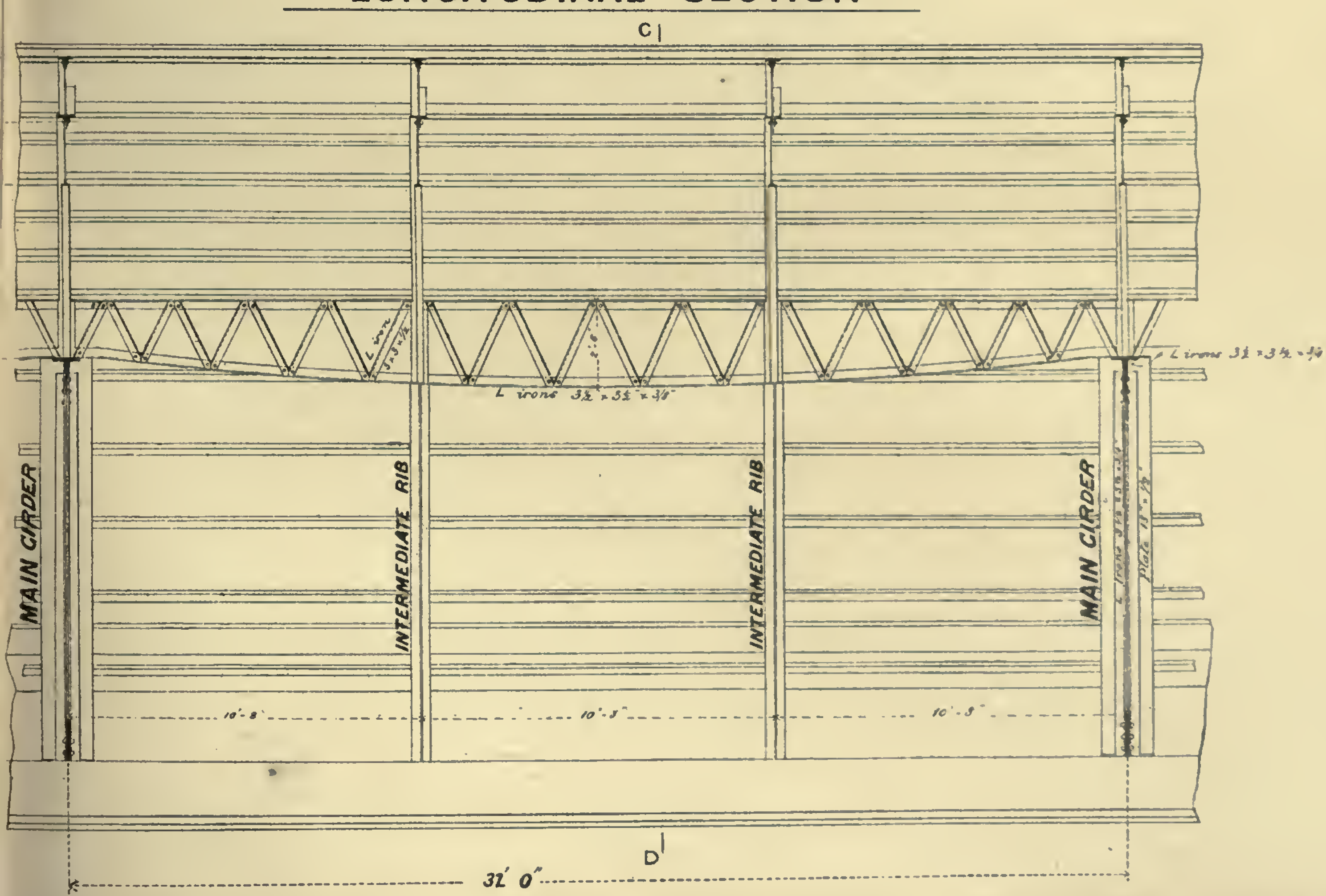
SECTION AT C.D.

...GOW

TRANSVERSE SECTION



LONCITUDINAL SECTION



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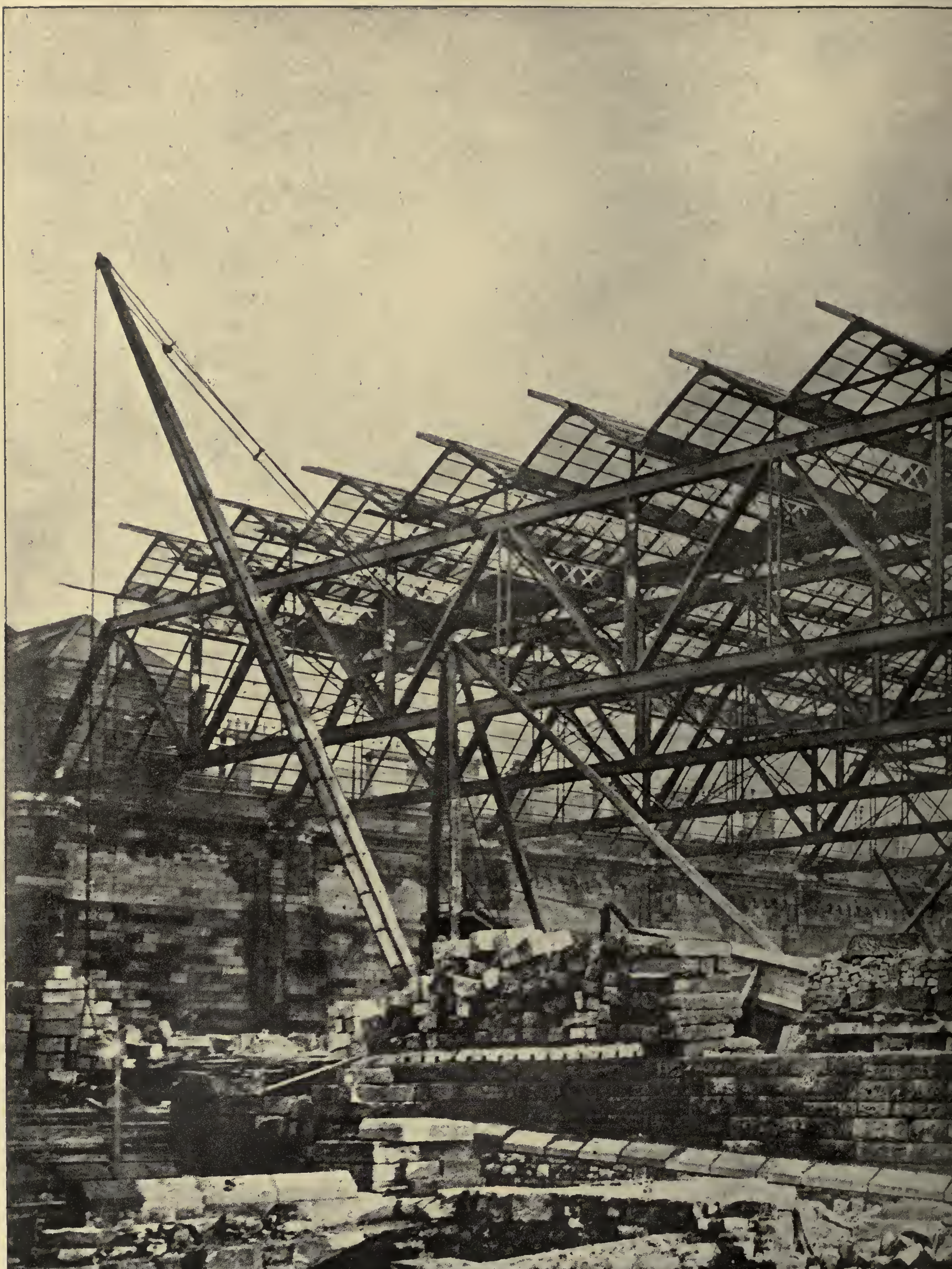
GLASGOW CENTRAL STA



ON

PLATE No. 7.

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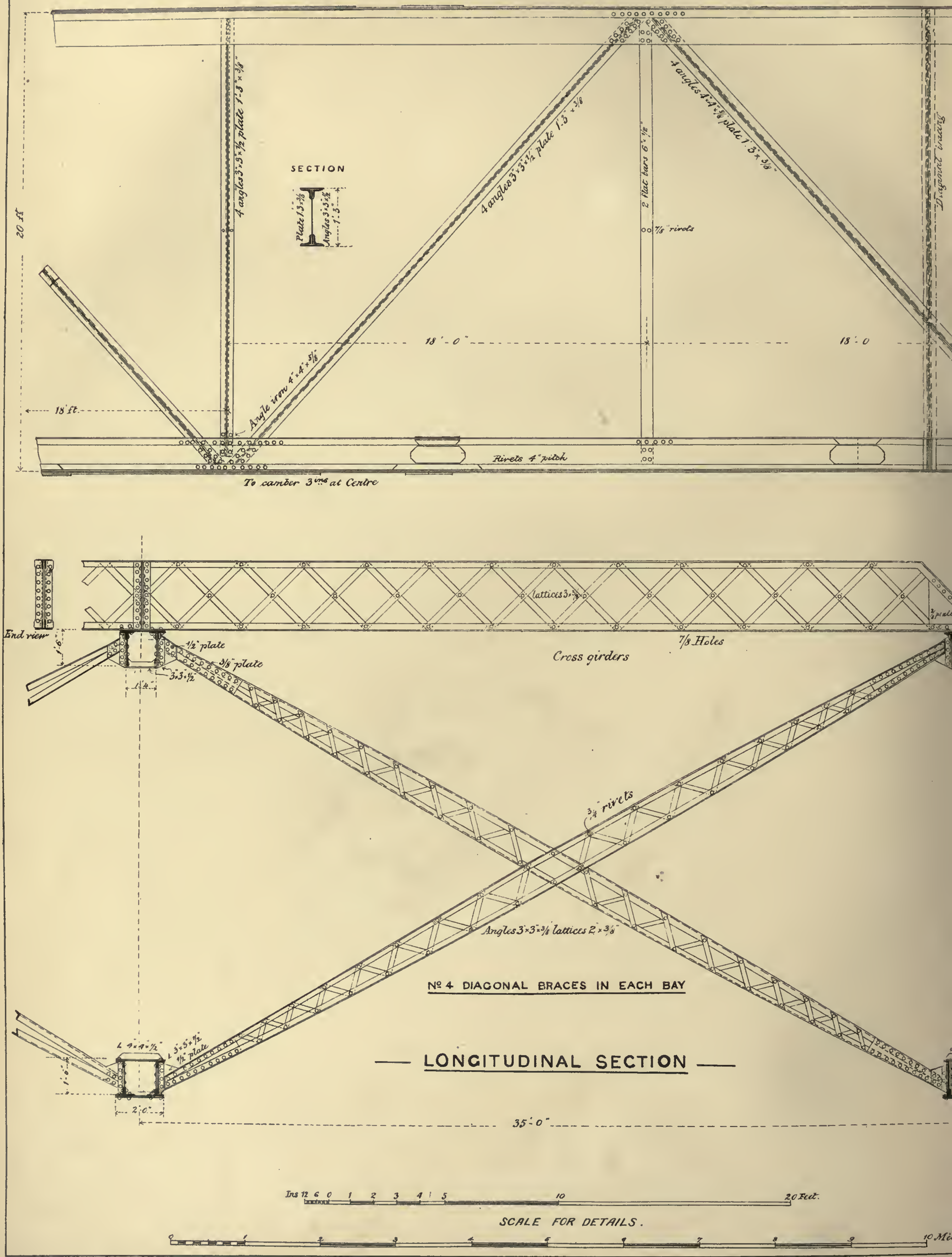
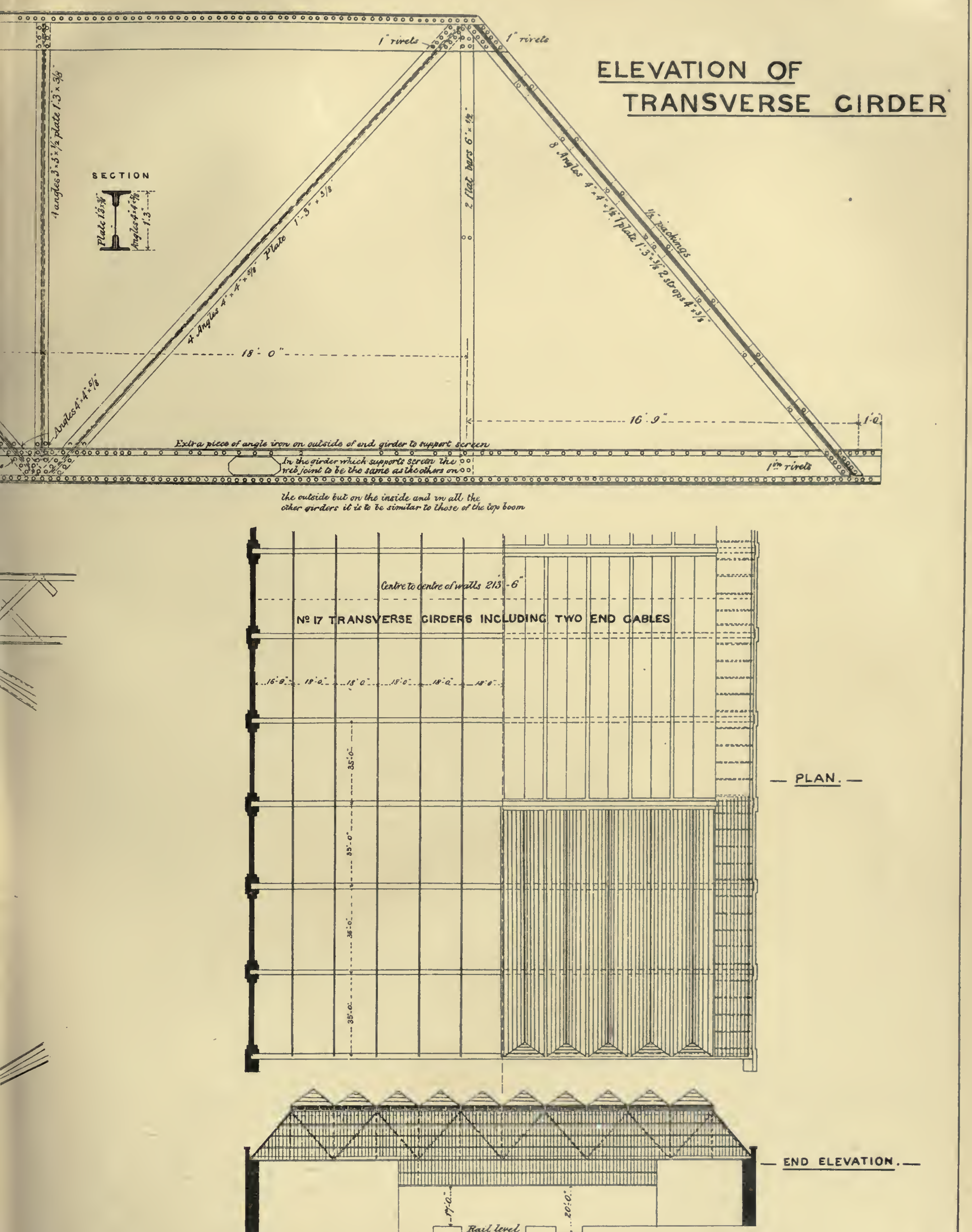
GLASCOW CENTRAL STATION

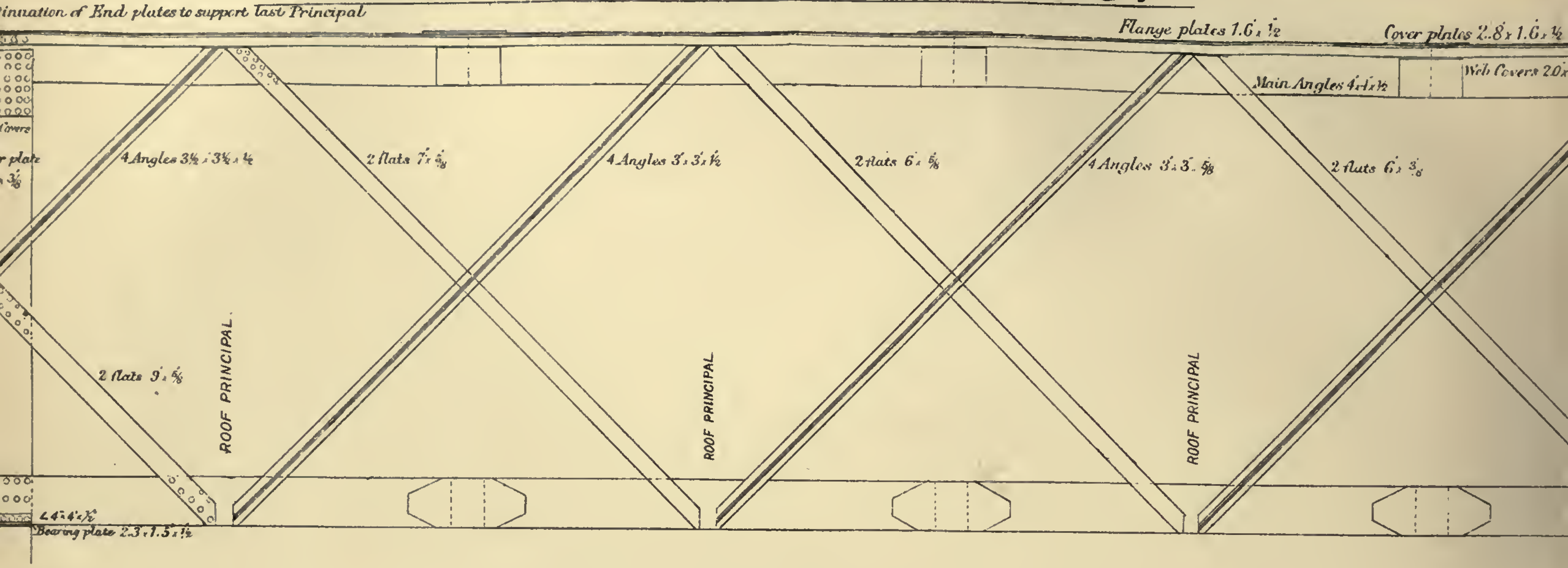


— LONGITUDINAL SECTION —

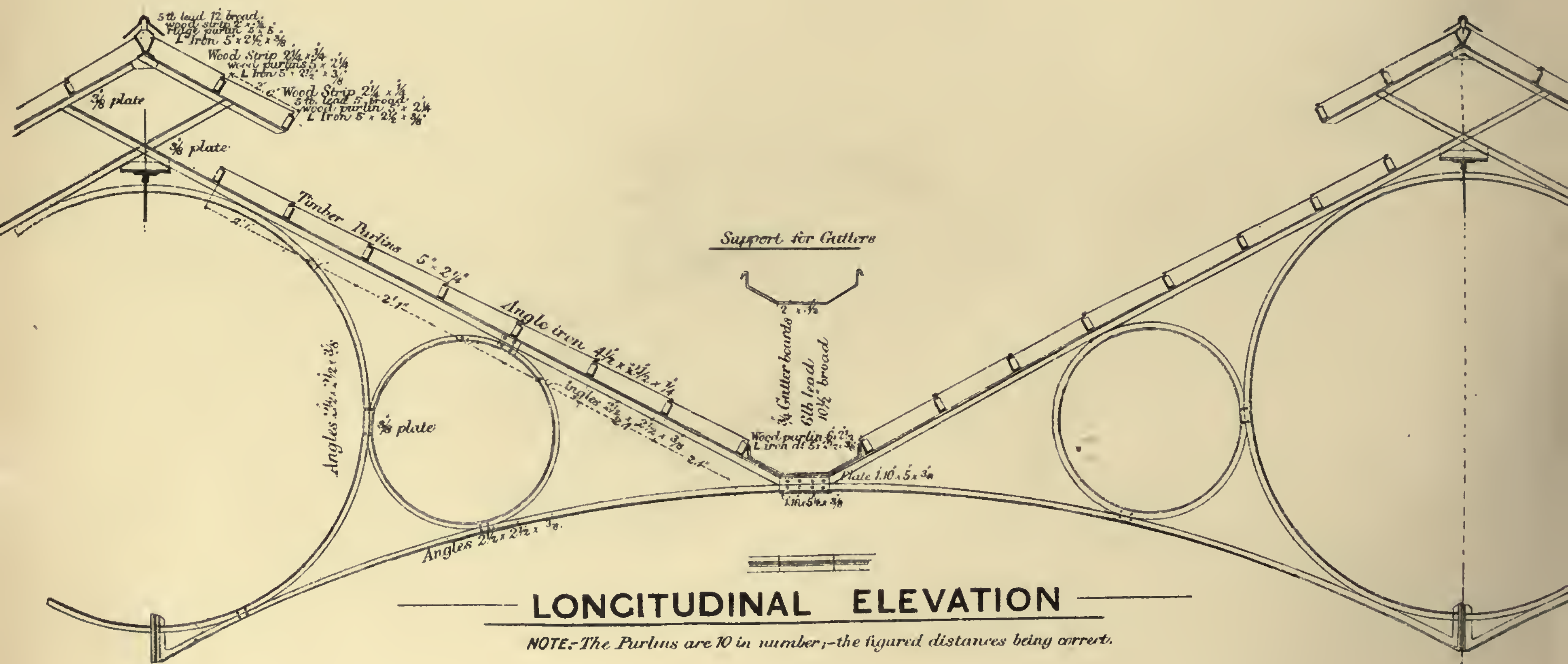


ELEVATION OF TRANSVERSE GIRDER
SECTION
Plate 1'3" x 3/4"
Angles 4" x 4" x 5/8"
1'3"
4 angles 3" x 3" x 1/2" plate 1'3" x 3/8"
1" rivets
1" rivets
2 flat bars 6" x 1/2"
4 Angles 4" x 4" x 5/8" Plate 1'3" x 3/8"
8 Angles 4" x 4" x 1/2" plate 1'3" x 3/8" 2 straps 4" x 3/8"
1/2" packings
Angles 4" x 4" x 5/8"
18' 0"
16' 9"
1' 0"
Extra piece of angle iron on outside of end girder to support screen
In the girder which supports screen the web joint to be the same as the others on the outside but on the inside and in all the other girders it is to be similar to those of the top boom
1in rivets
Centre to centre of walls 213' - 6"
No 17 TRANSVERSE GIRDERS INCLUDING TWO END GABLES
16' 0"
18' 0"
18' 0"
18' 0"
18' 0"
18' 0"
35' 0"
35' 0"
35' 0"
35' 0"
PLAN.
END ELEVATION.
17' 0"
20' 0"
Rail level

CARLISLE STATION ROOF



ELEVATION OF TRANSV



LONCITUDINAL ELEVATION

NOTE:–*The Purlins are 10 in number;–the figured distances being correct.*

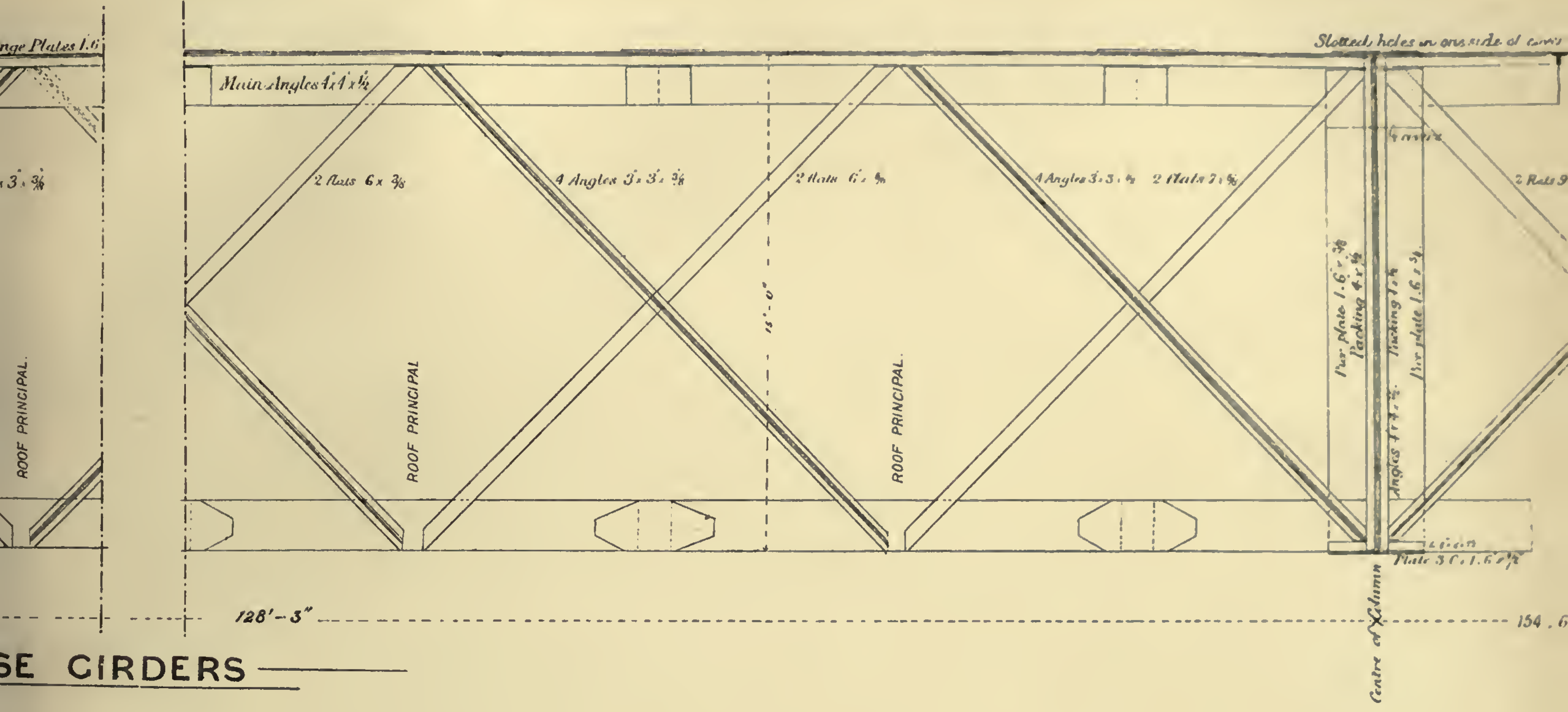
40' 6¾"

ROOF PRINCIPALS 15 FEET APART

SCALE

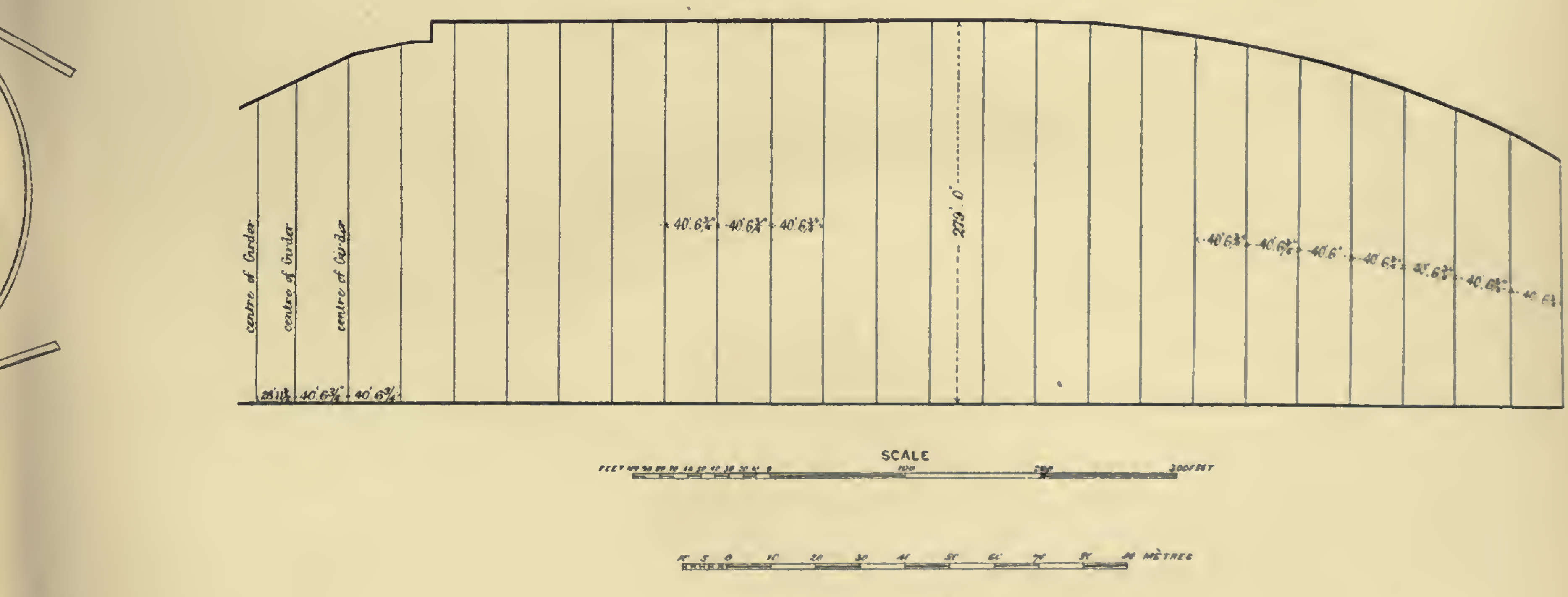
INCHES 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 FEET

1 0 1 2 3 METRES.



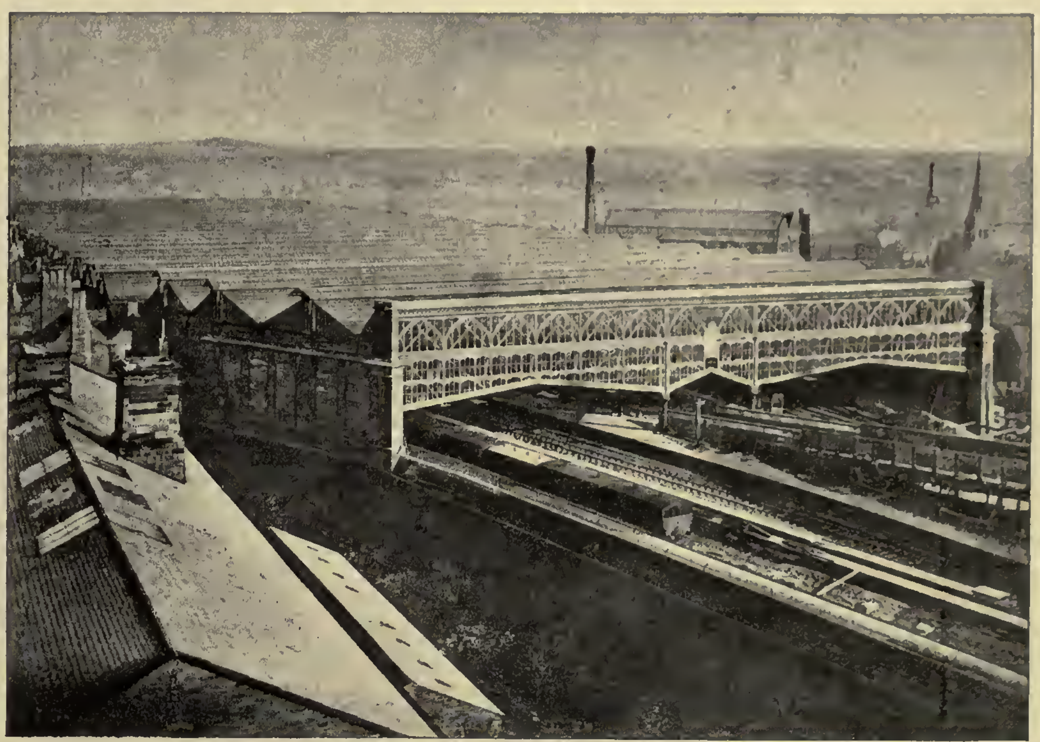
SE GIRDERS

PLAN



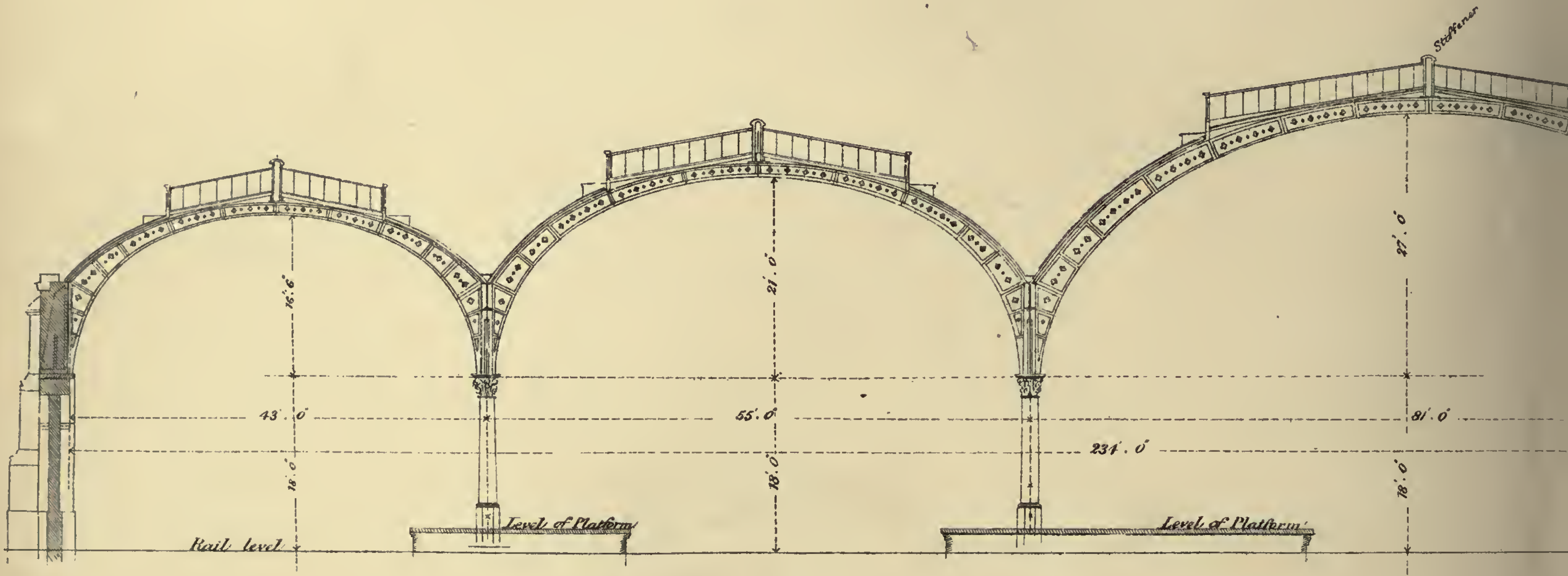
CARLISLE STATION

"INK-PHOTO", SPRAGUE & Cº. LONDON.



N . E . R.

YORK NEW STATION

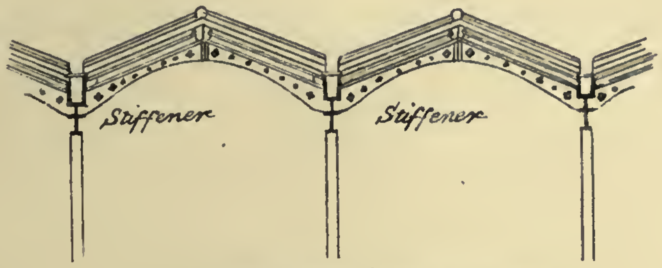


TRANSVERSE SECTION THROUGH STATIO

SCALE.

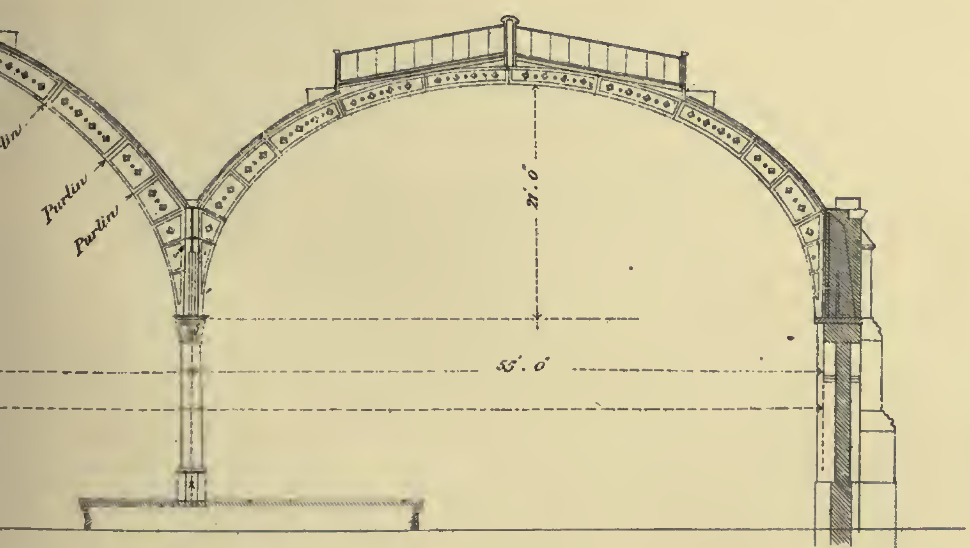
Feet 10 5 0 10 20 30 40 50 60

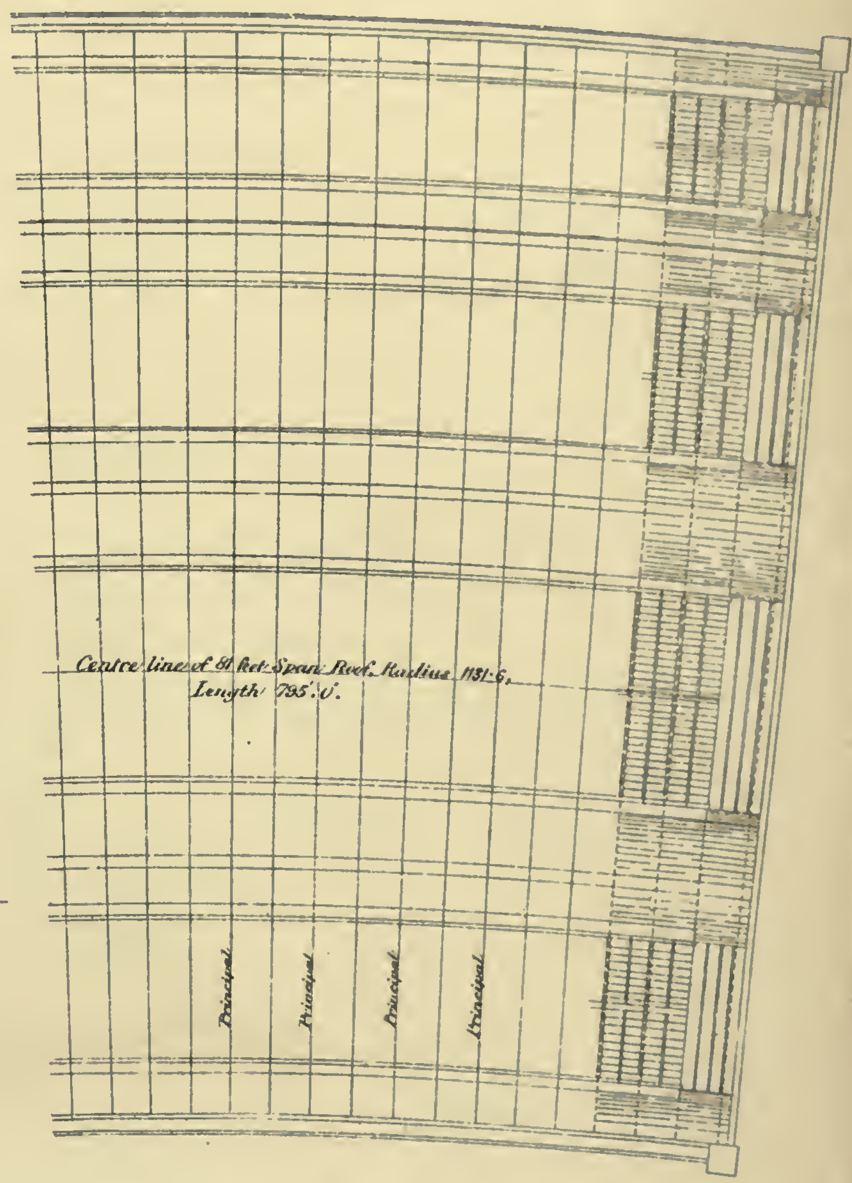
Centimètres 100 0 10 20



PART LONGITUDINAL SECTION THROUGH SKYLIGHTS

Scale
Feet 0 5 10 20 Feet
Centimètres 100 0 1 2 3 4 5 Mètres





PART ROOF PLAN

80 90 100 Feet
30 Mètres

SCALE.
Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet
Centimètres 100 0 10 20 30 Mètres

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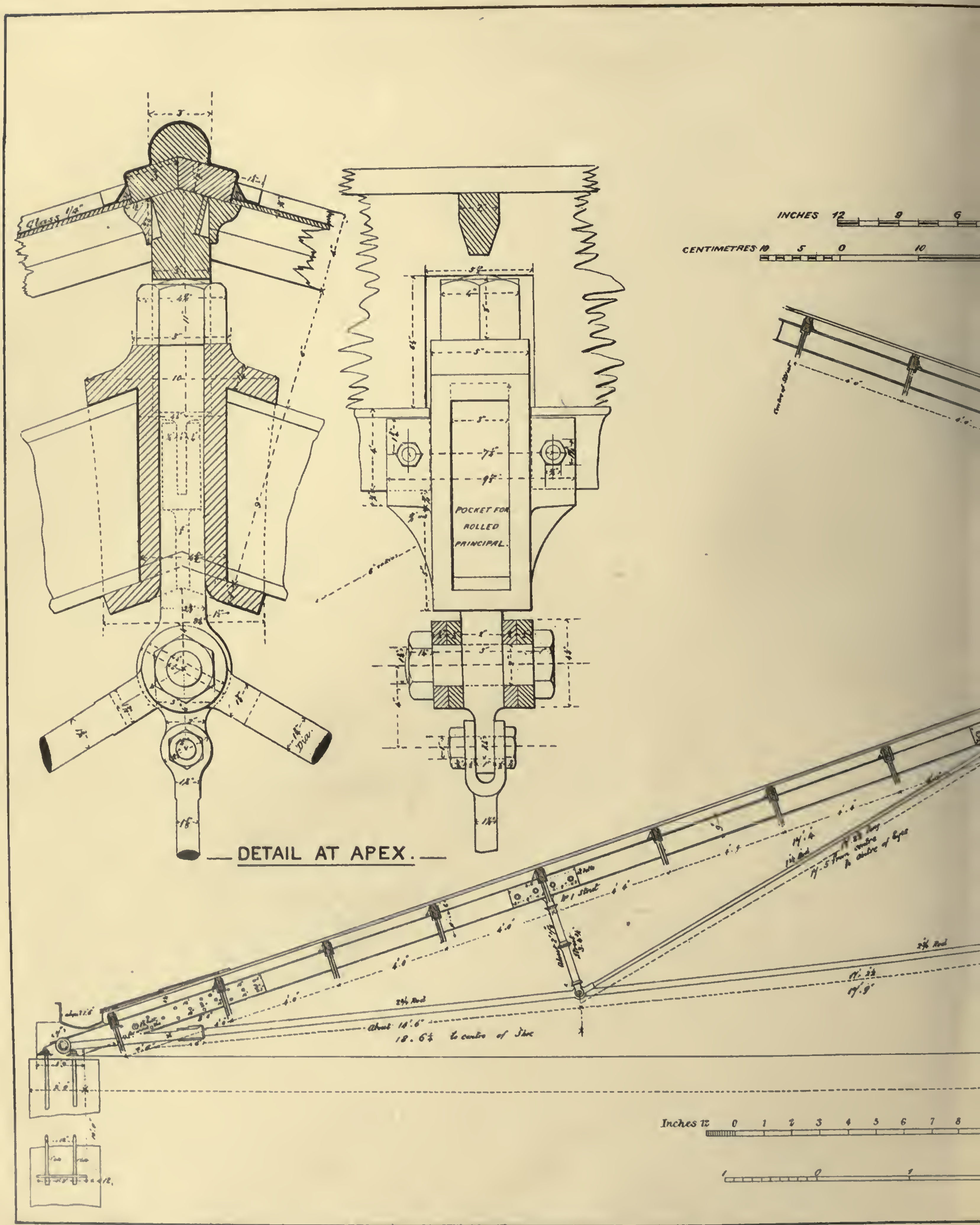
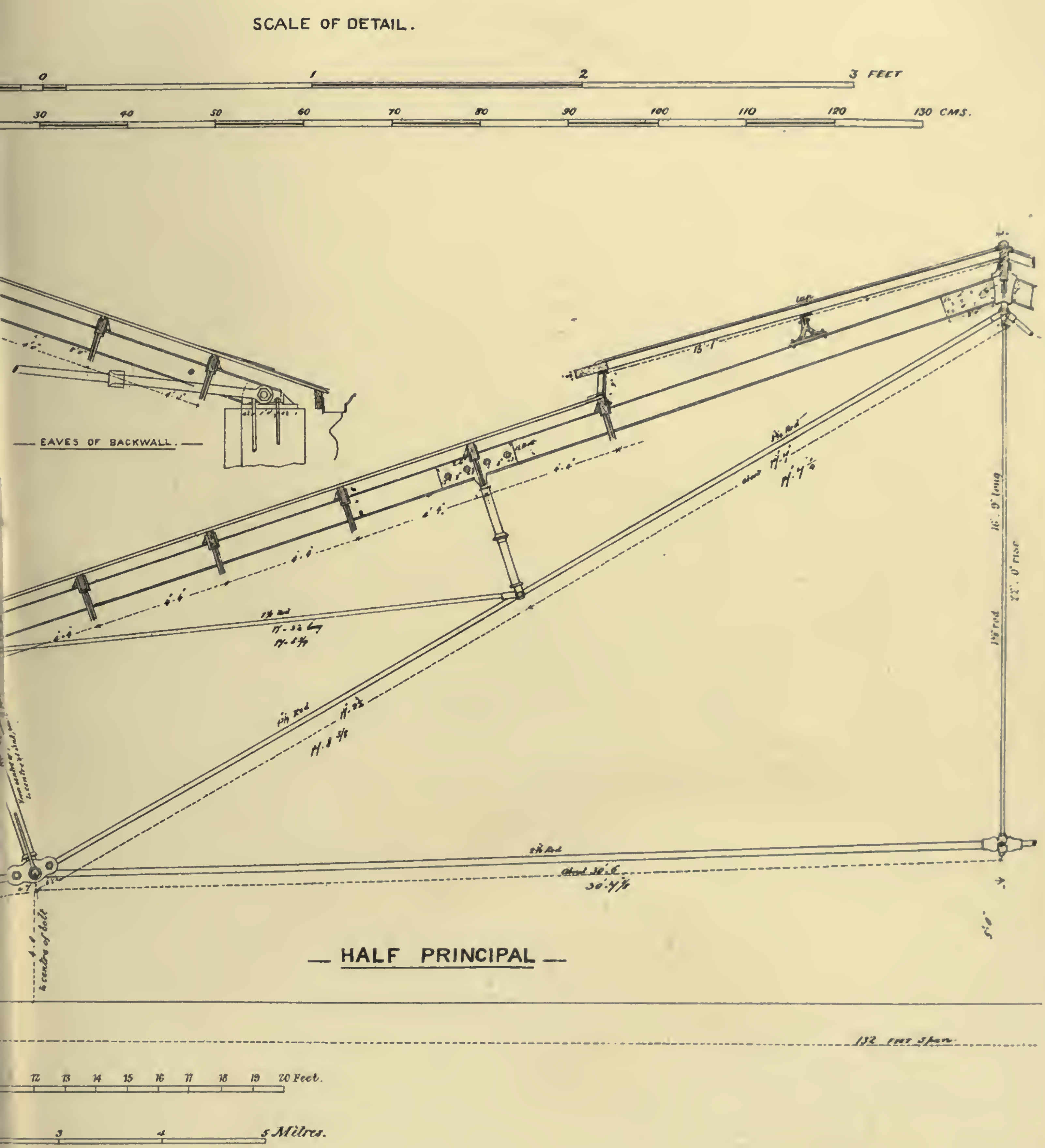

DETAIL AT APEX.
Glass 1/4"
POCKET FOR ROLLED PRINCIPAL.
INCHES 12 9 6
CENTIMETRES 10 5 0 10
Inches 12 0 1 2 3 4 5 6 7 8

ST. DAVID'S STATION EXETER



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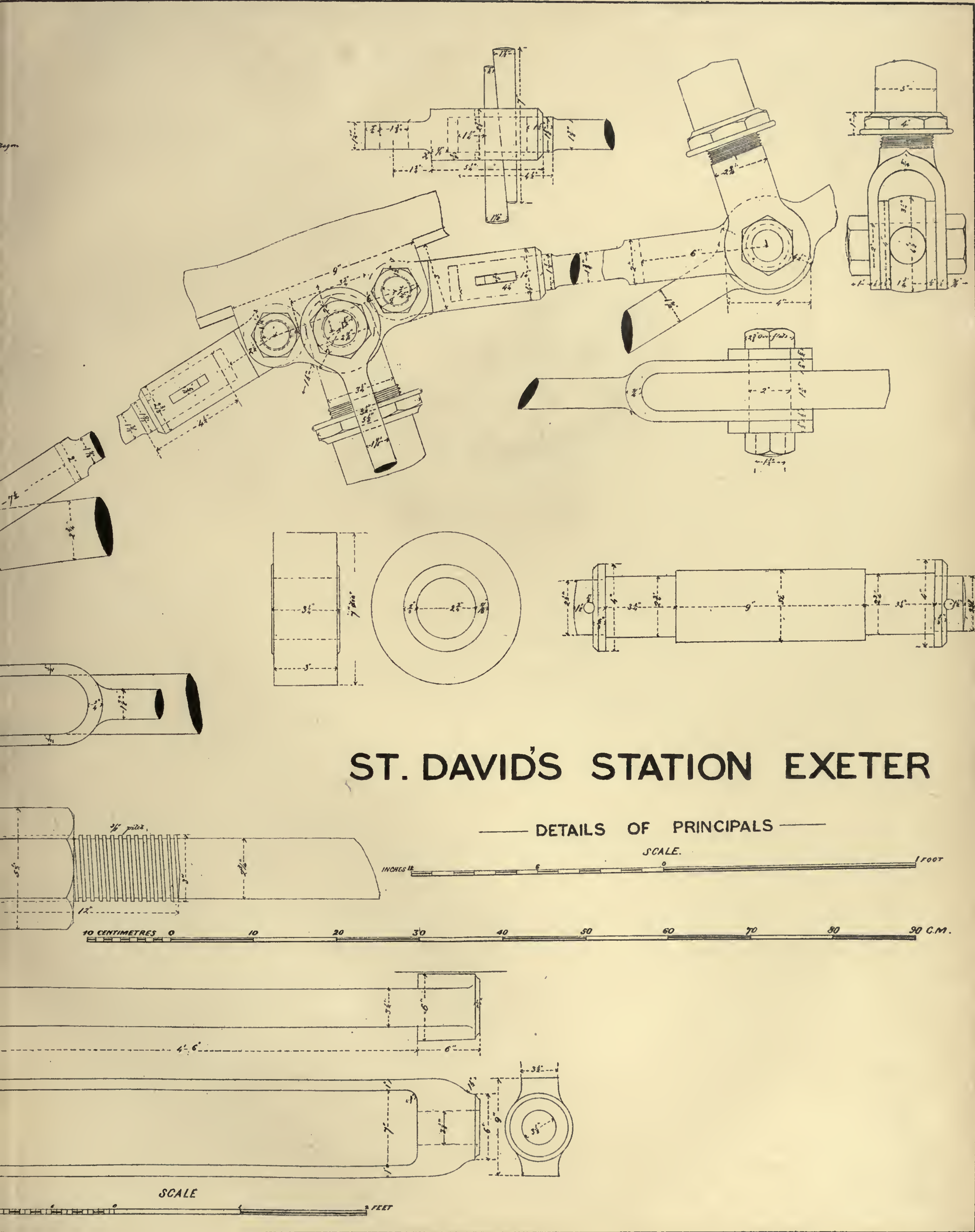

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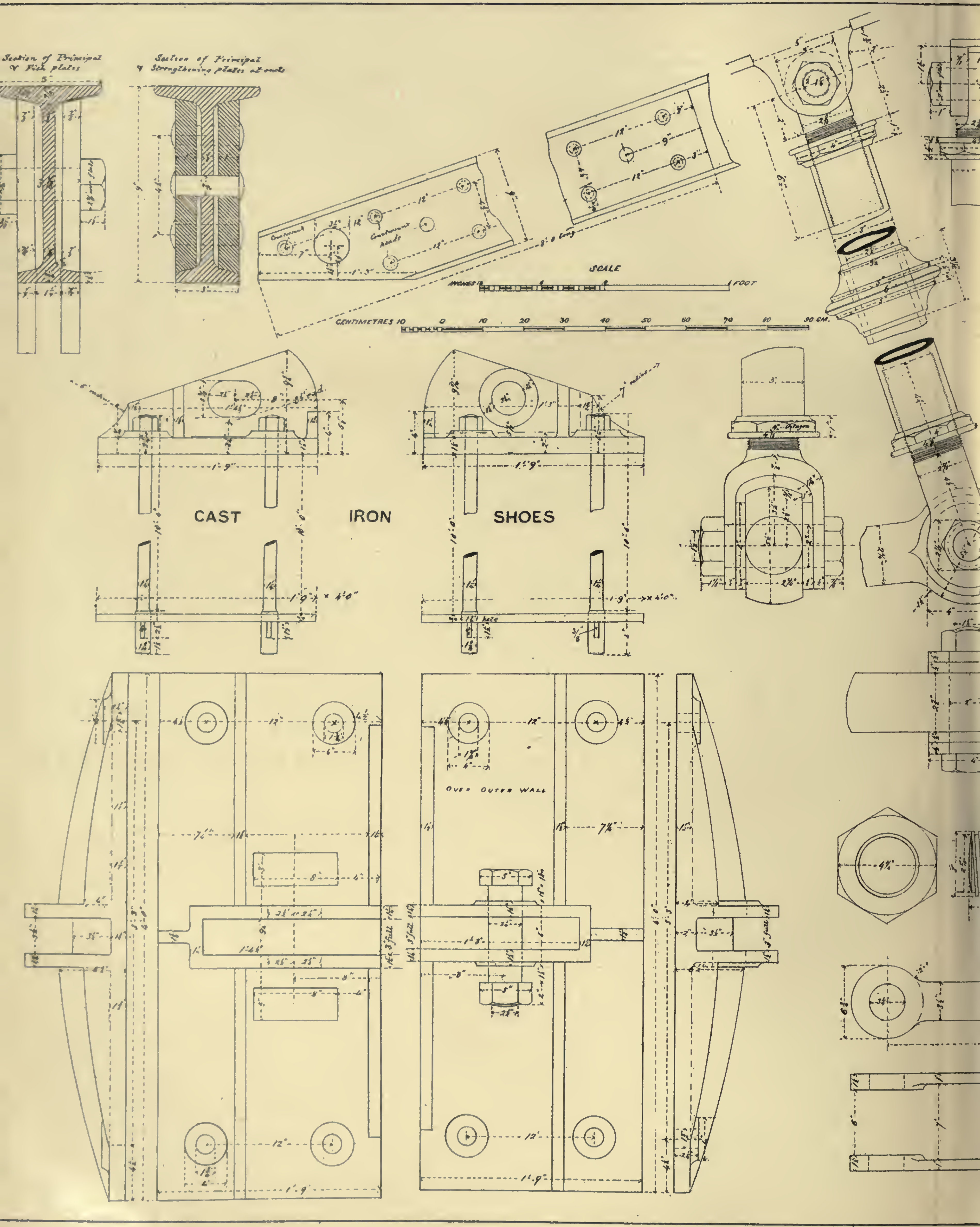
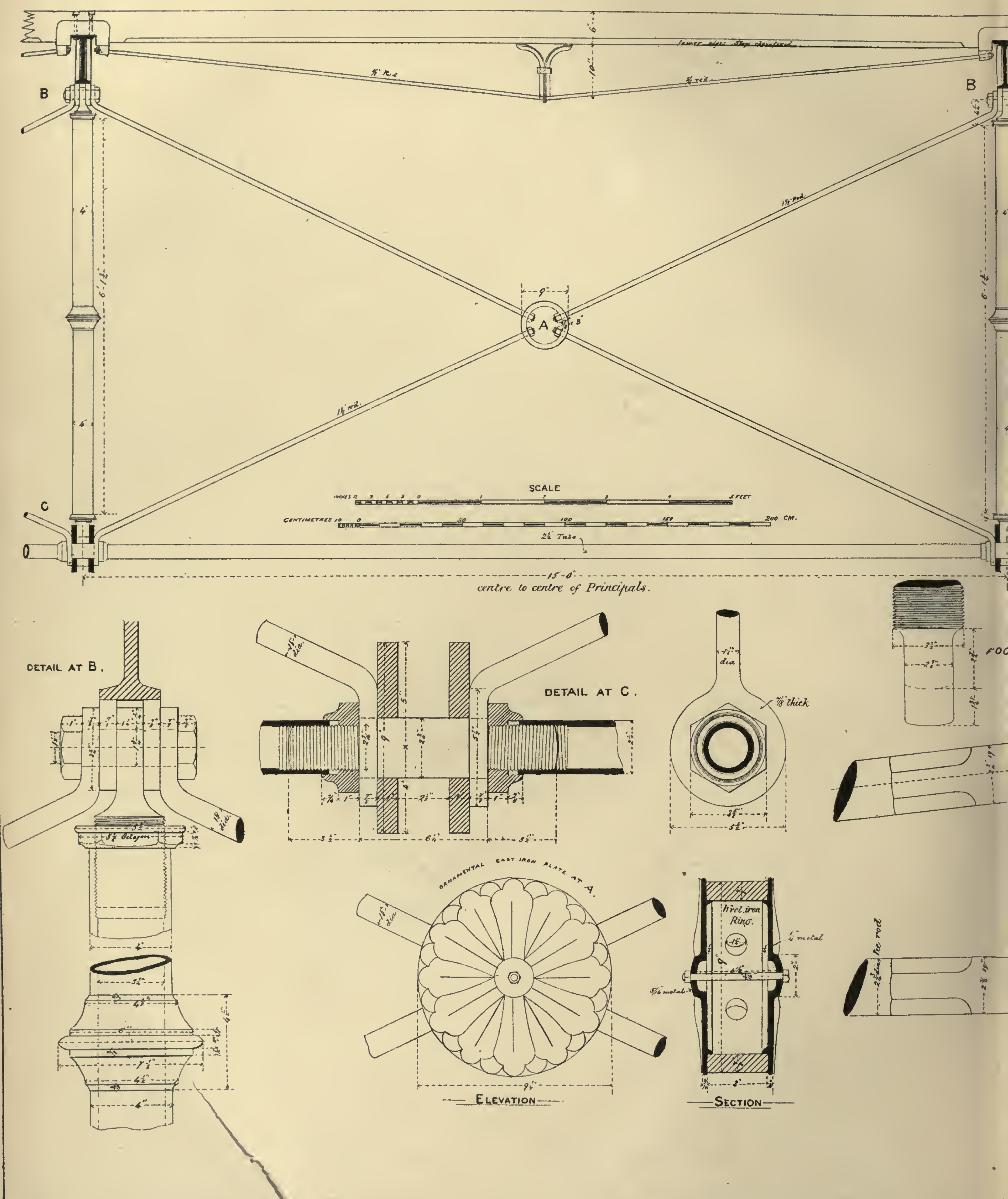
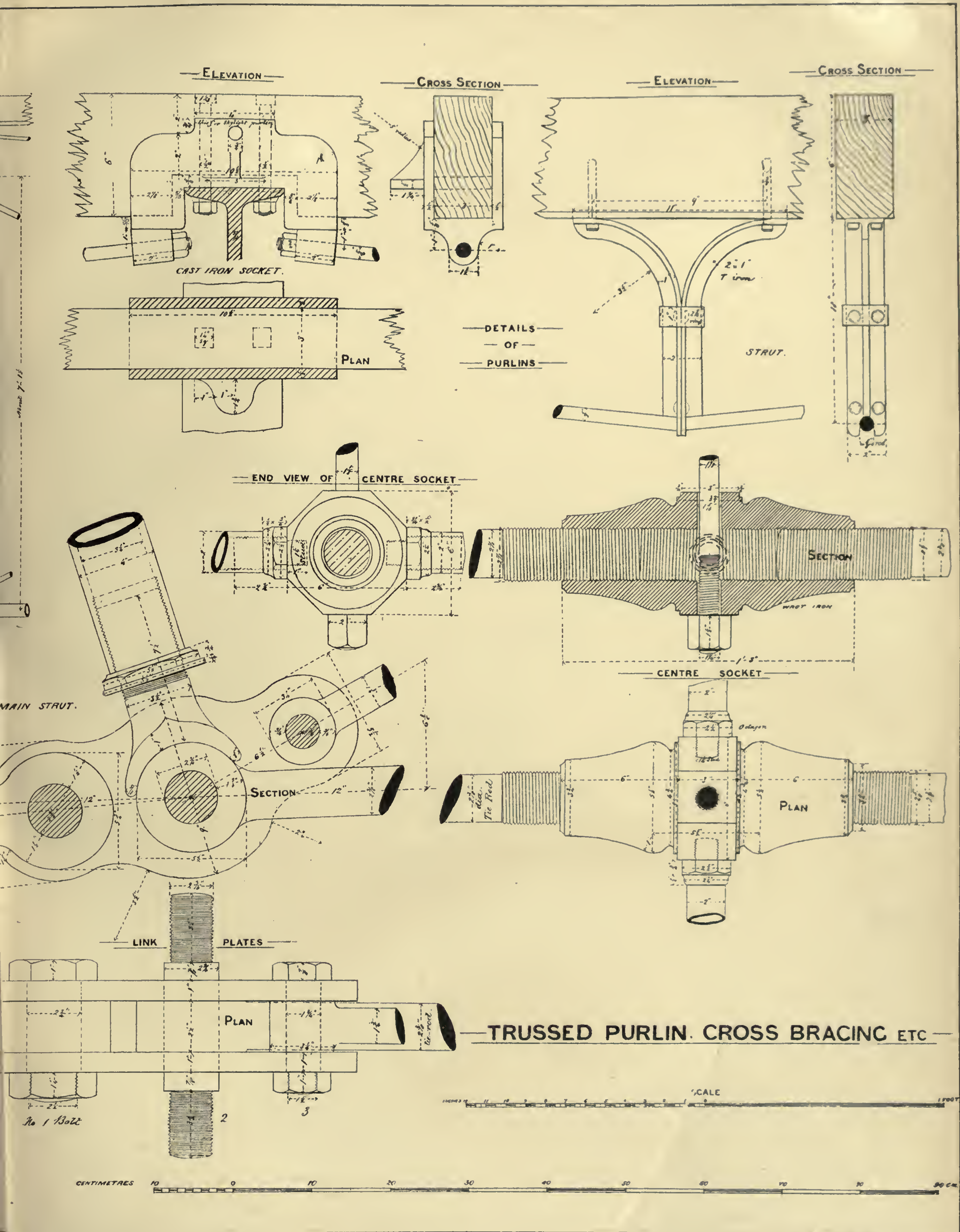


Section of Principal & Fish plates
Section of Principal & Strengthening plates at ends
SCALE
INCHES 12
FOOT
CENTIMETRES 10 0 10 20 30 40 50 60 70 80 90 CM.
CAST IRON SHOES
OVER OUTER WALL

ST. DAVID'S STATION EXETER





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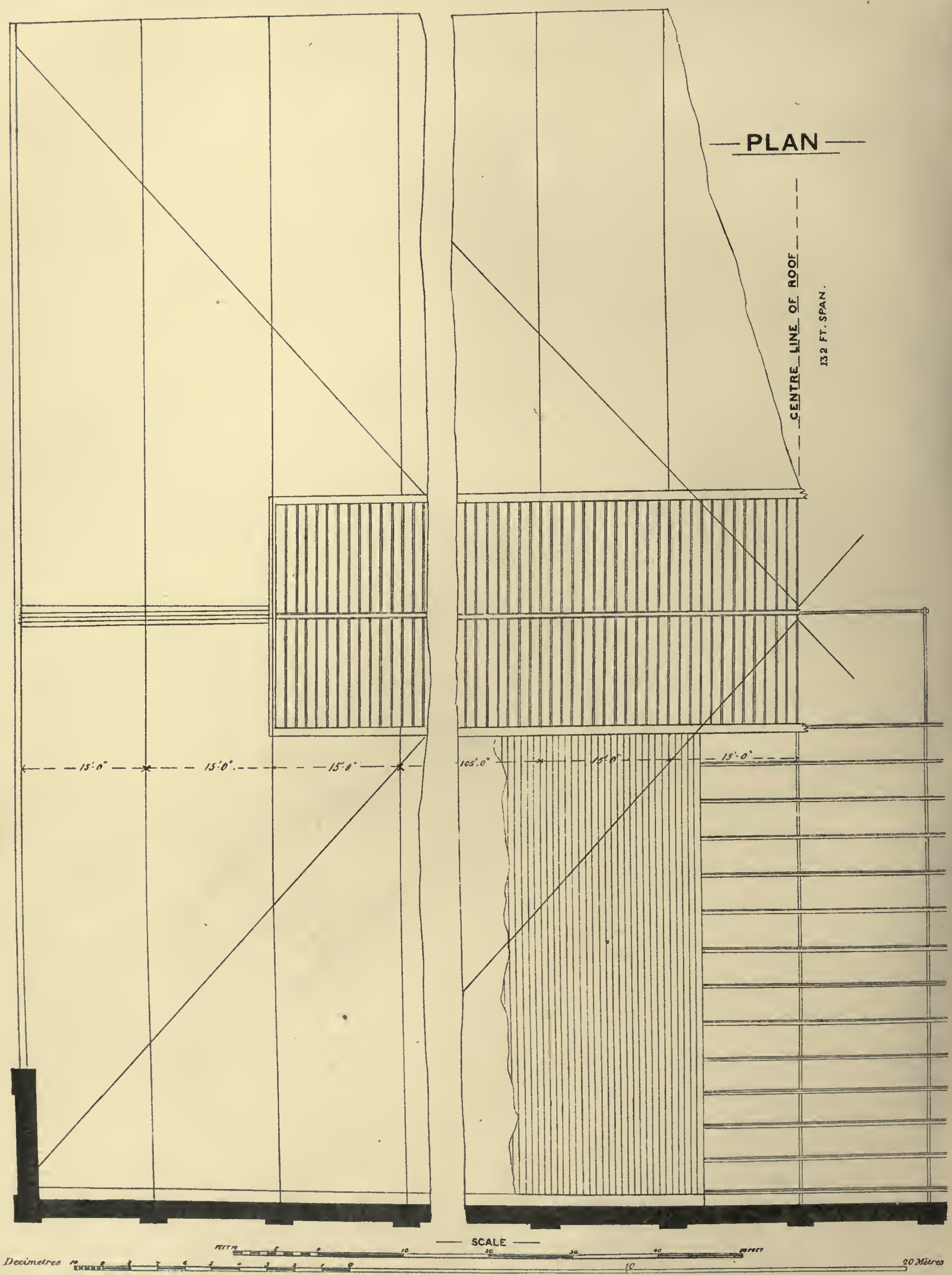
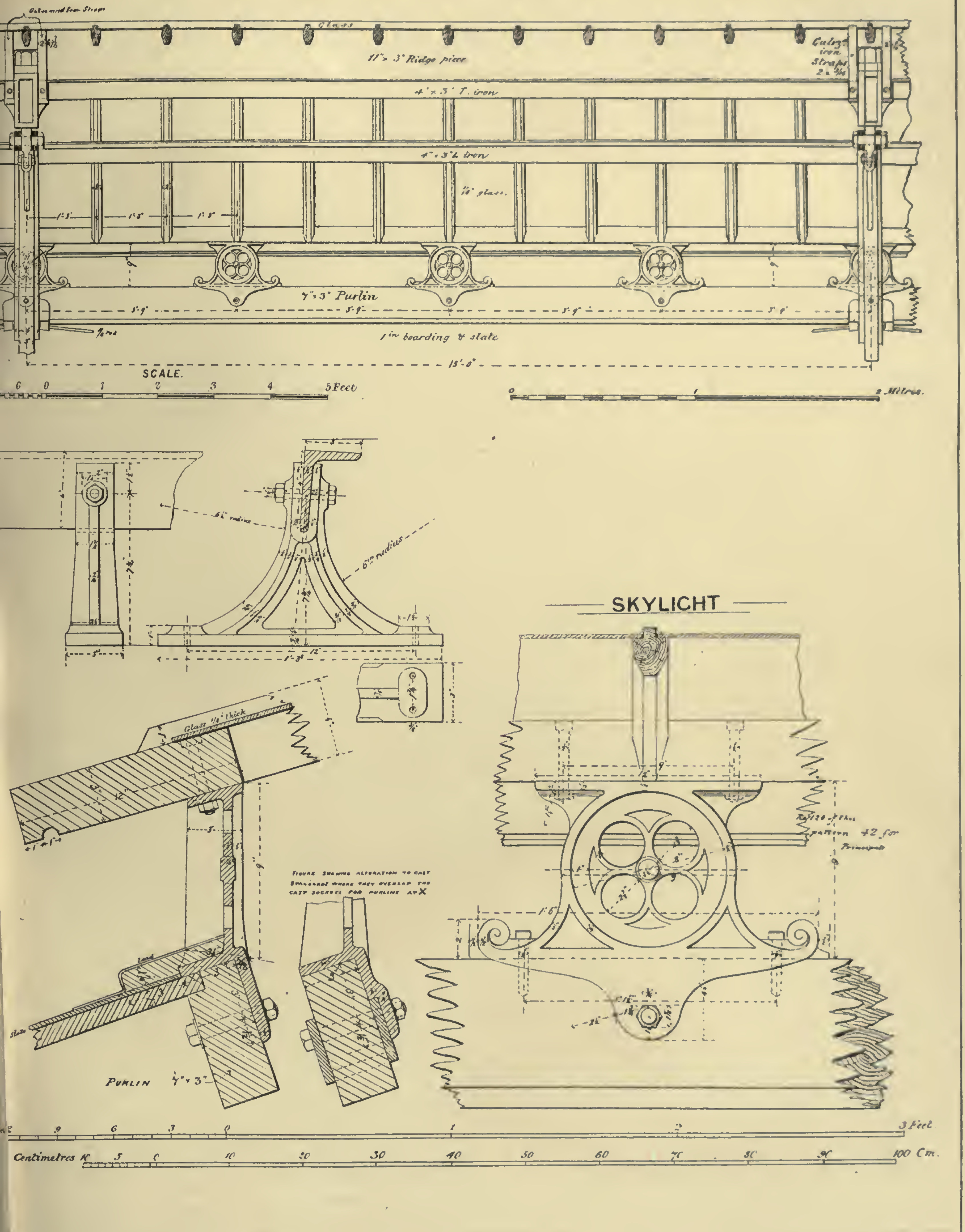
ST. DAVID'S STATION EXETER





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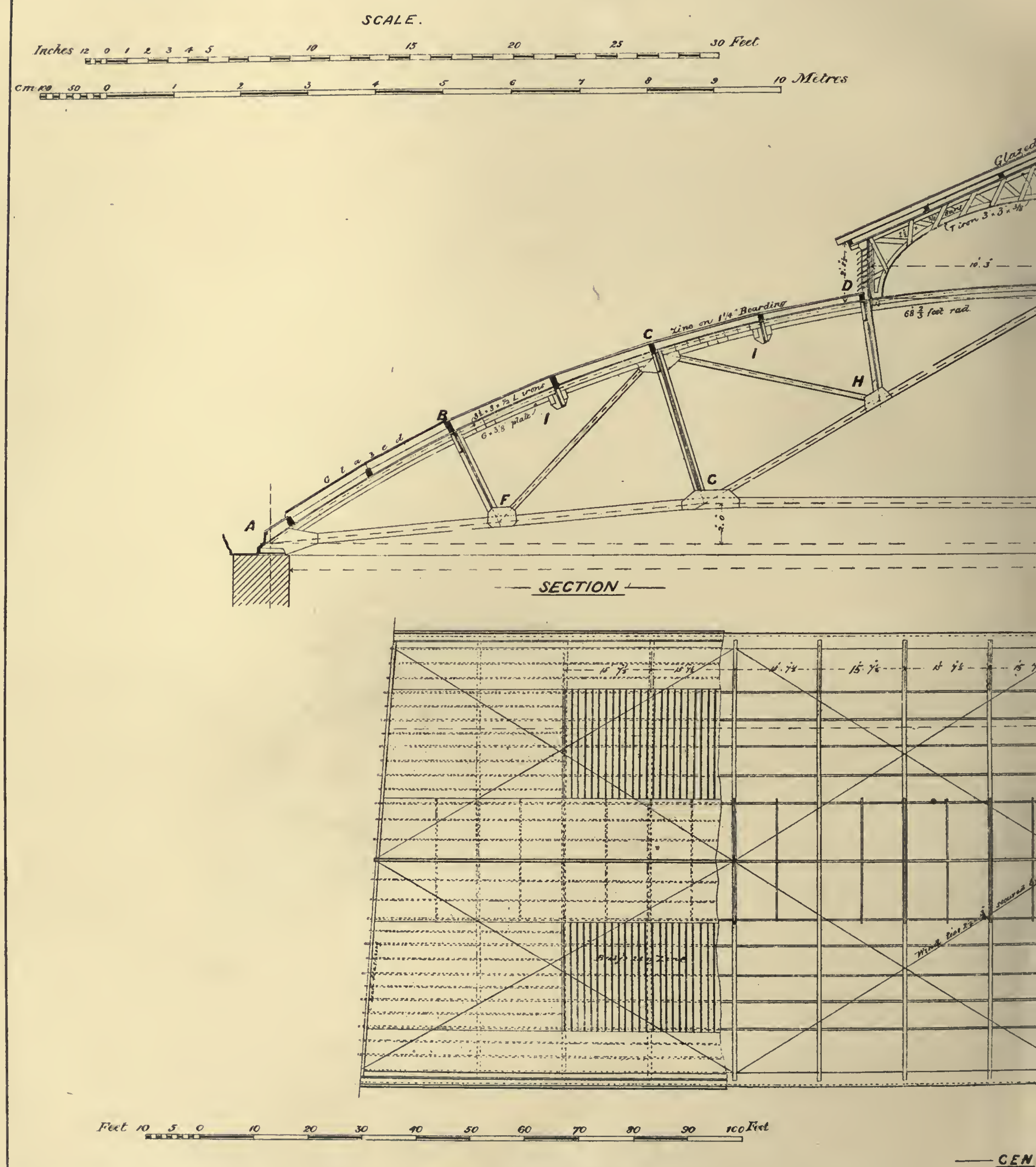
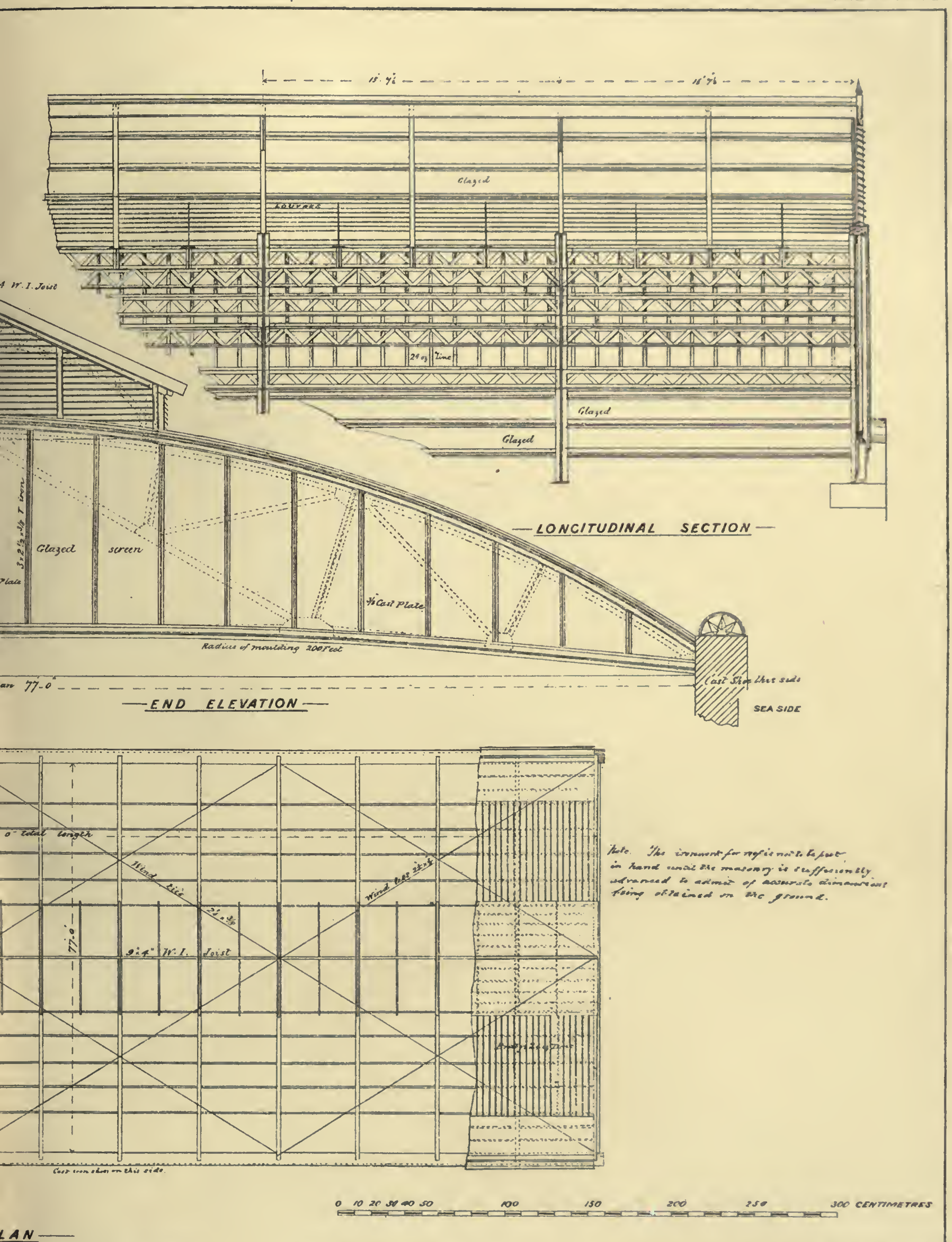
GREAT WESTERN RAILWAY

— PENZANCE NEW STATION ROOF —





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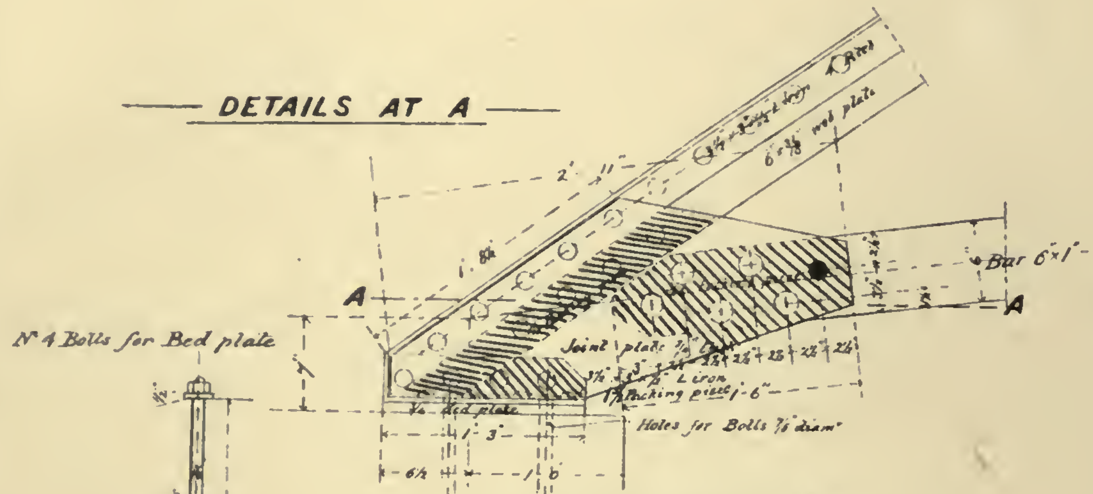
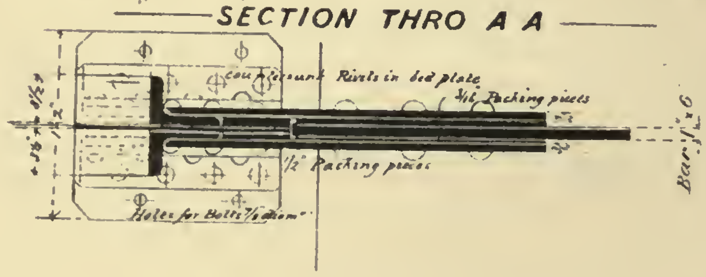
PENZANCE STATION ROOF, C.W.R.

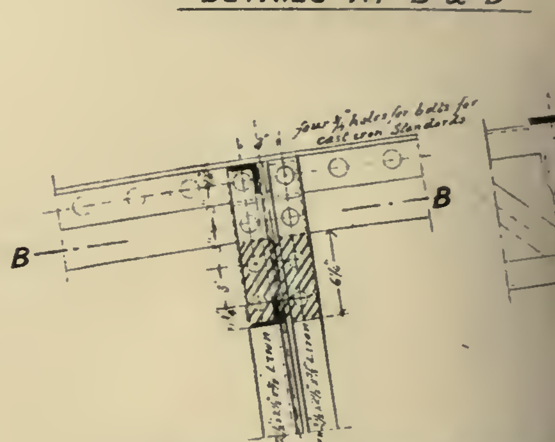
DETAILS AT A



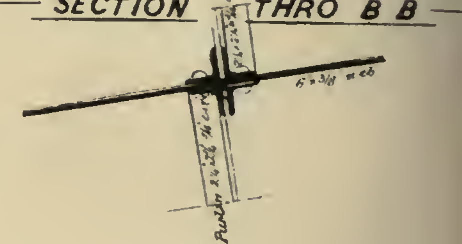
SECTION THRO A A



DETAILS AT B & D

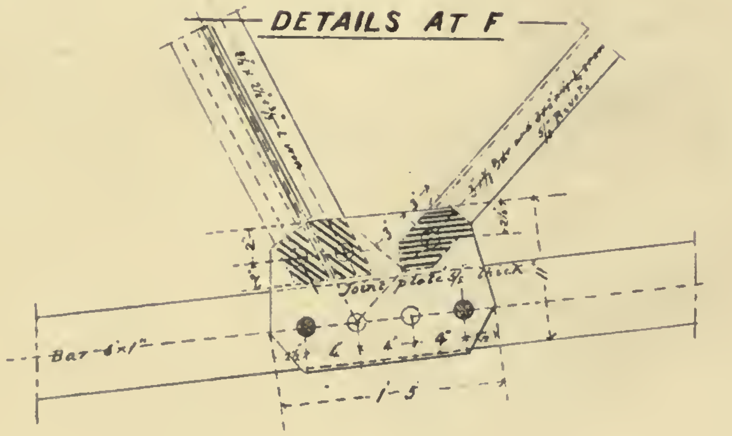


SECTION THRO B B

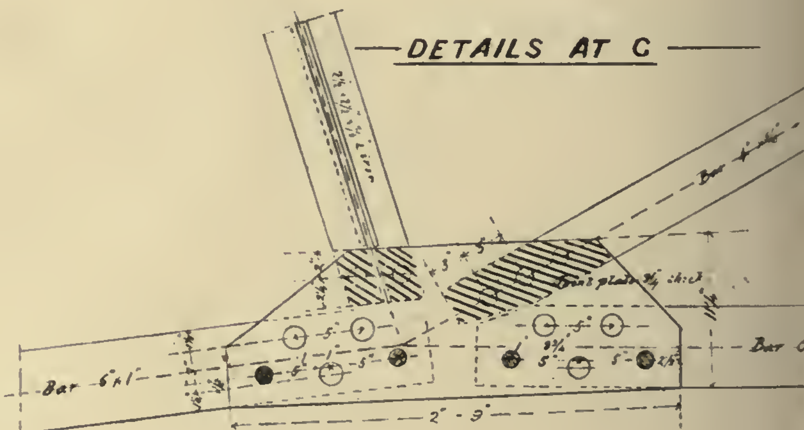


NOTE, PACKING PIECES ARE SHOWN WIT

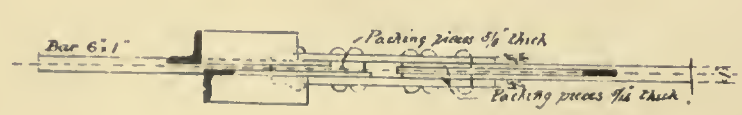
DETAILS AT F



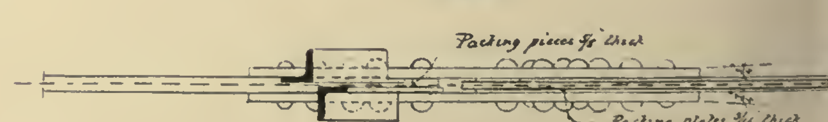
DETAILS AT C

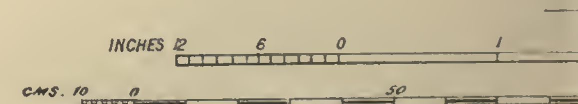


PLAN

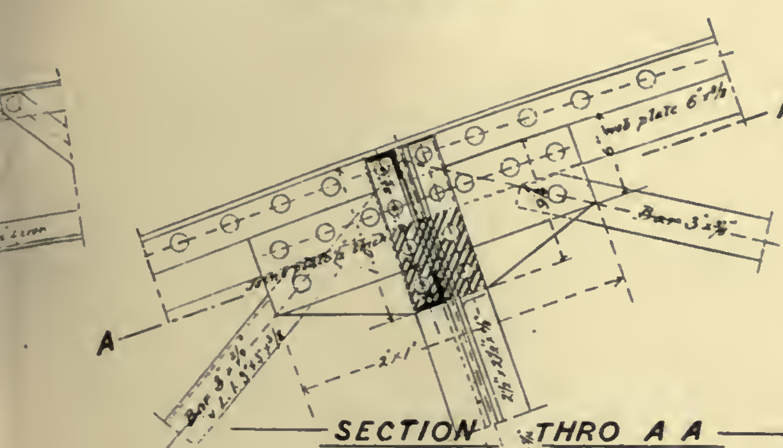


PLAN



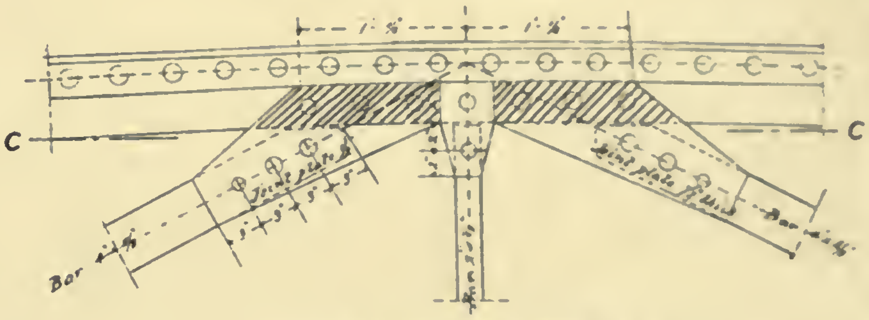


DETAILS AT C

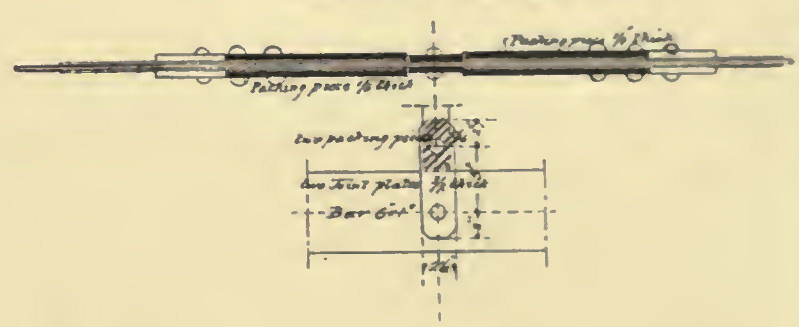


SECTION THRO A A

DETAILS AT E

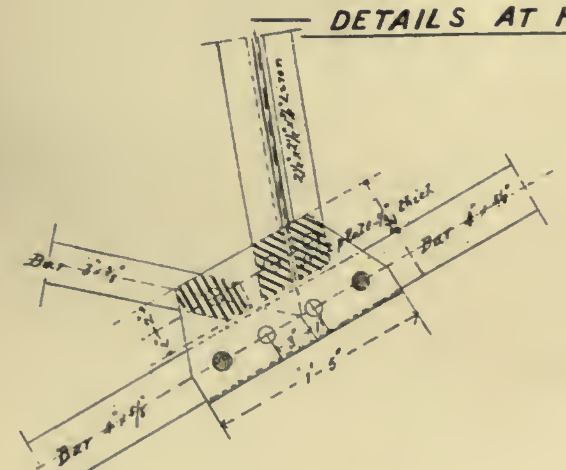


SECTION THRO C C



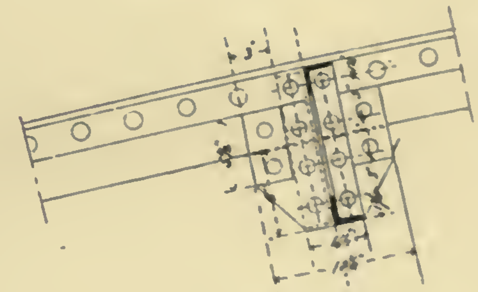
LINES IN THE DETAILS.

DETAILS AT H

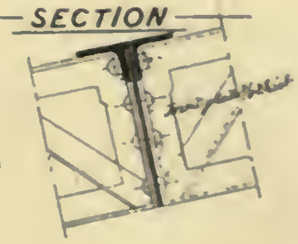


PLAN

DETAILS AT I & I



SECTION



PLAN

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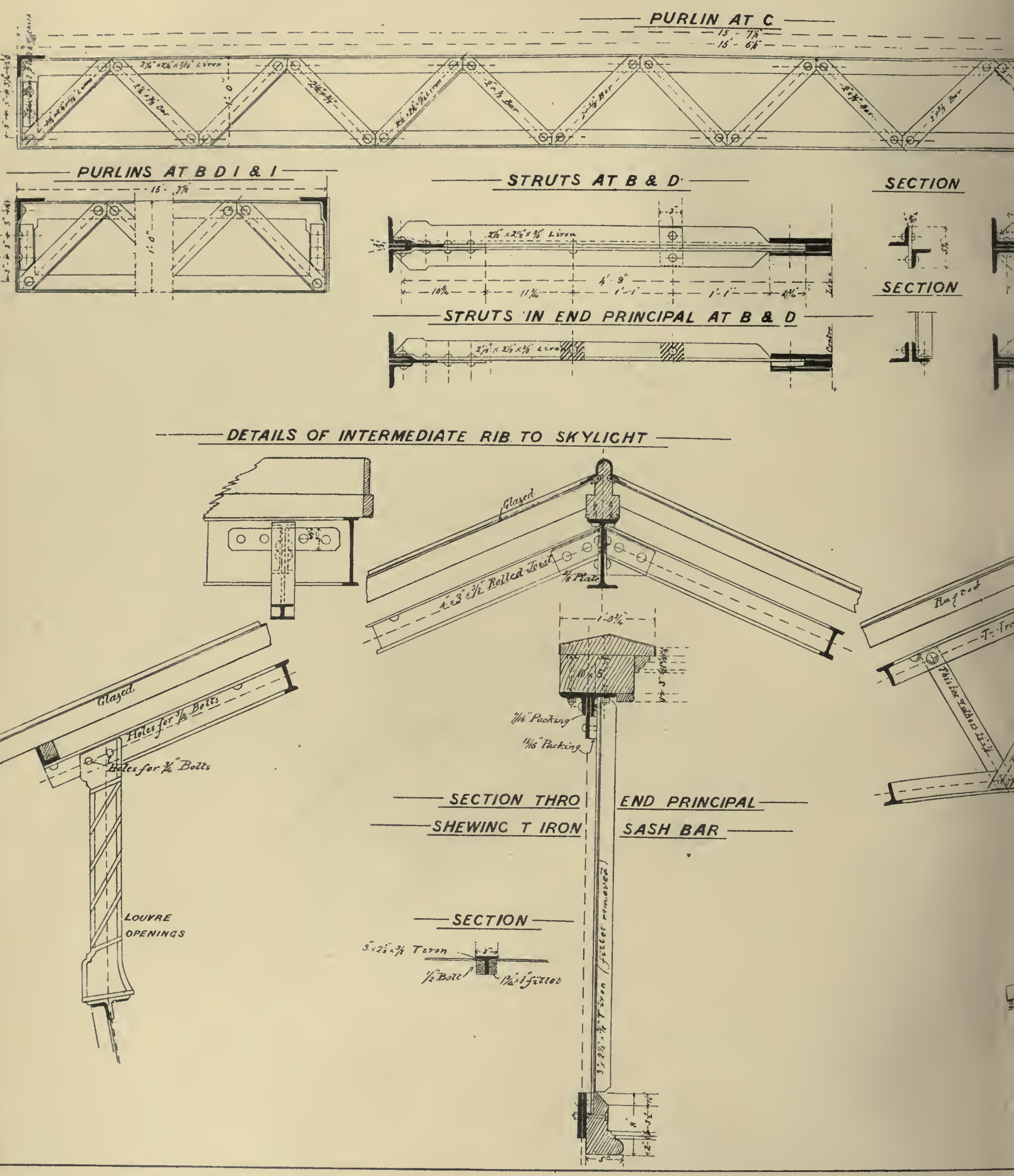
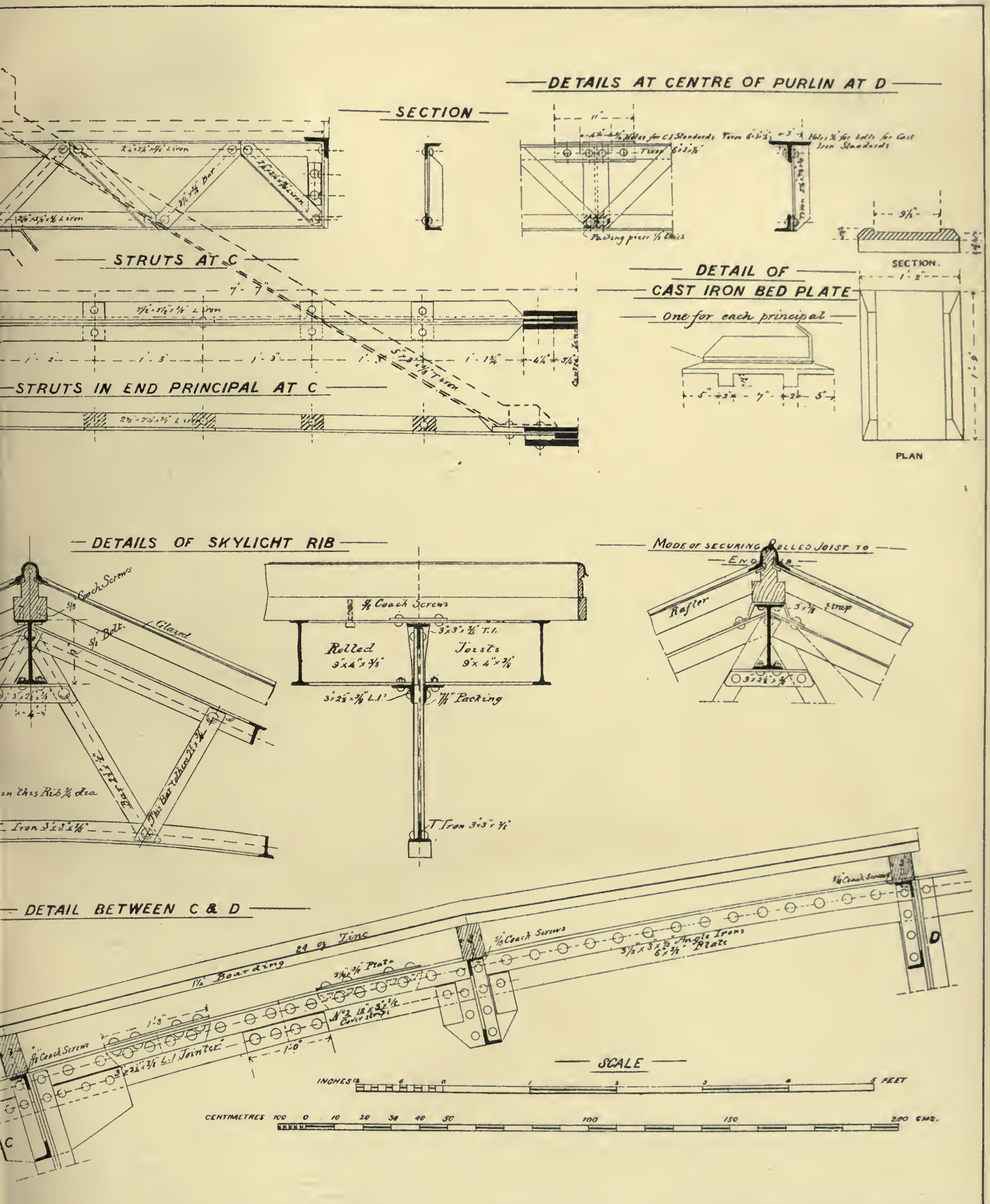
PENZANCE STATION ROOF, G.W.R.





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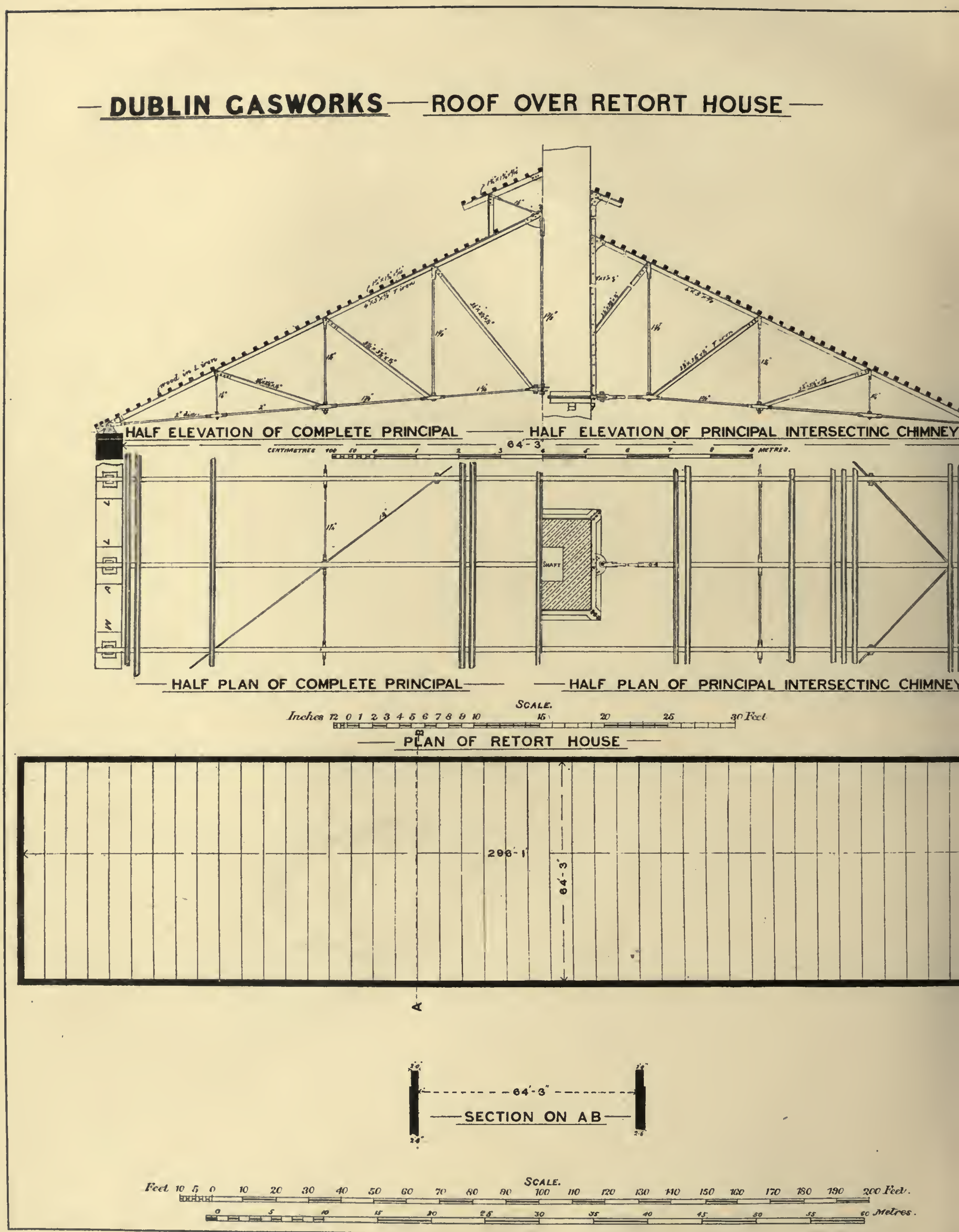
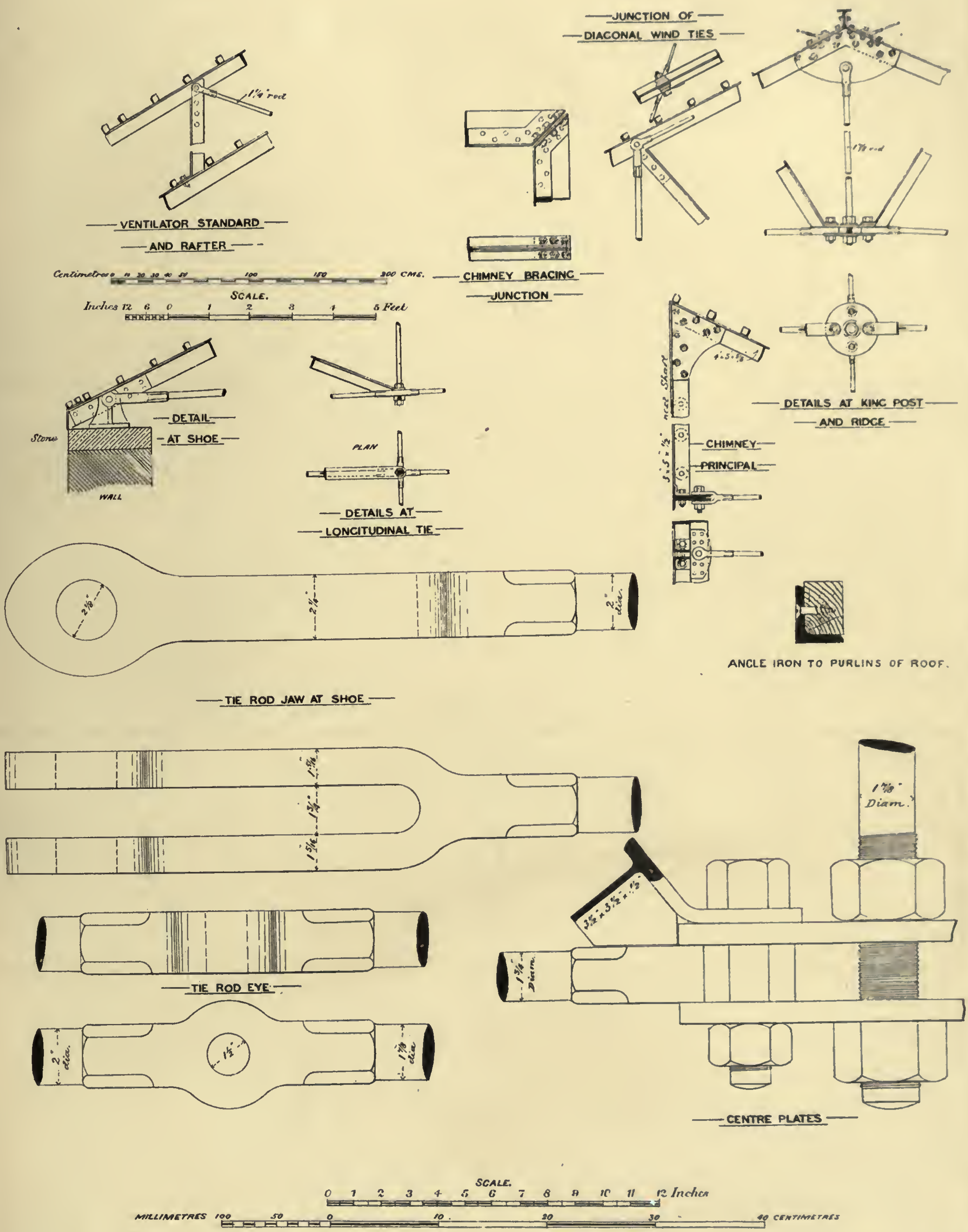


DUBLIN GASWORKS — ROOF OVER RETORT HOUSE
HALF ELEVATION OF COMPLETE PRINCIPAL
HALF ELEVATION OF PRINCIPAL INTERSECTING CHIMNEY
64'-3"
CENTIMETRES
METRES
SHAFT
HALF PLAN OF COMPLETE PRINCIPAL
HALF PLAN OF PRINCIPAL INTERSECTING CHIMNEY
SCALE.
Inches 12 0 1 2 3 4 5 6 7 8 9 10 15 20 25 30 Feet
PLAN OF RETORT HOUSE
296'-1"
64'-3"
A
B
64'-3"
SECTION ON AB
SCALE.
Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 Feet.
0 5 10 15 20 25 30 35 40 45 50 55 60 Metres.


JUNCTION OF
DIAGONAL WIND TIES
1¼" rod
VENTILATOR STANDARD
AND RAFTER
CHIMNEY BRACING
JUNCTION
SCALE.
DETAIL
AT SHOE
Stone
WALL
PLAN
DETAILS AT
LONGITUDINAL TIE
DETAILS AT KING POST
AND RIDGE
CHIMNEY
PRINCIPAL
ANGLE IRON TO PURLINS OF ROOF.
TIE ROD JAW AT SHOE
TIE ROD EYE
1⅞" Diam.
CENTRE PLATES
SCALE.
0 1 2 3 4 5 6 7 8 9 10 11 12 Inches
MILLIMETRES 100 50 0 10 20 30 40 CENTIMETRES

—SWANSEA STATION—

—DETAILS OF ROOF—

SCALE OF ELEVATION

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 FEET

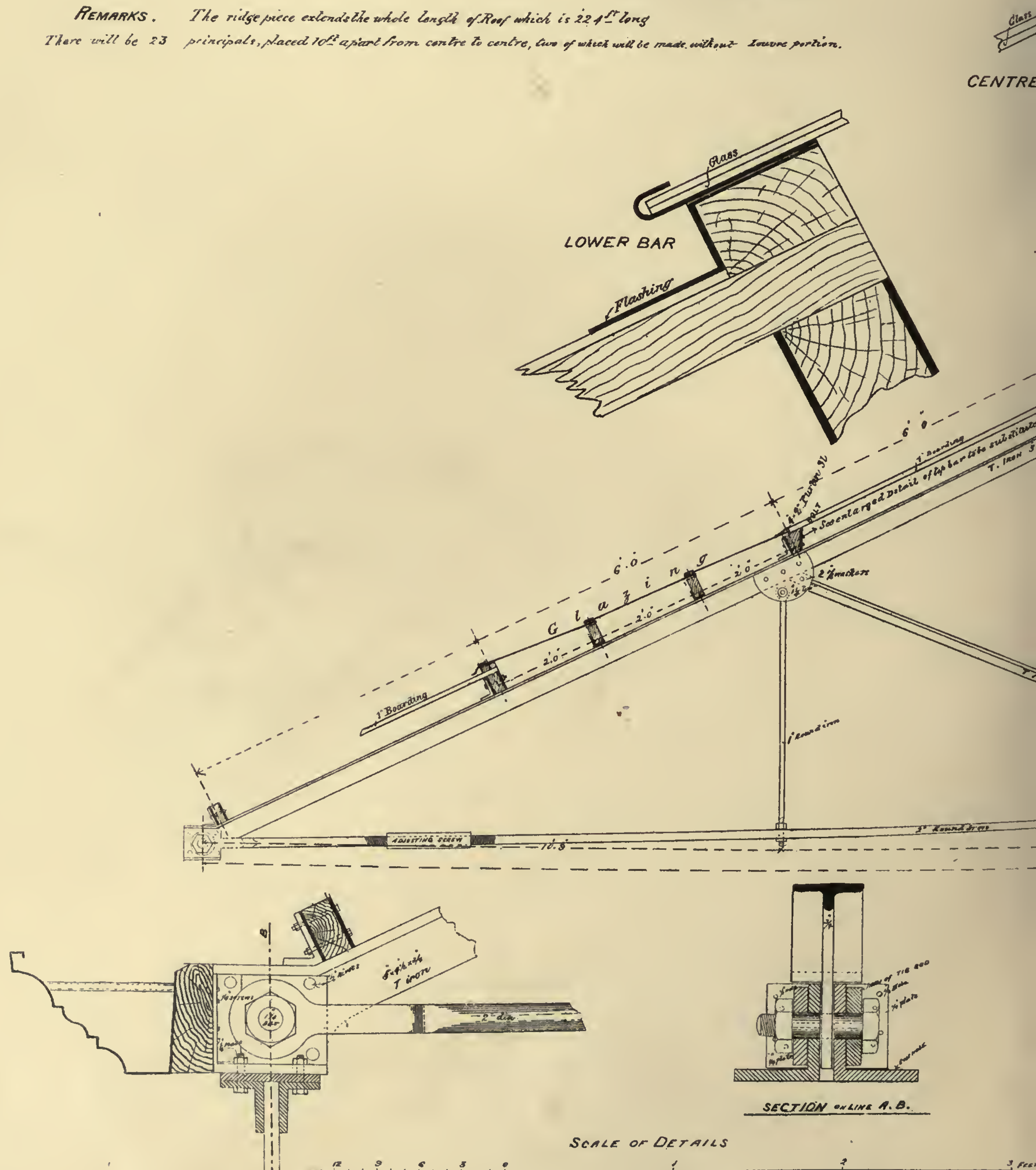
CENTIMETRES 100 50 0 1 2 3 METRES.

SCALE FOR GLAZING.

0 1 2 3 4 5 6 7 8 9 10 11 12 INCHES

0 10 50 100 150 200 250 300 Millimetres.

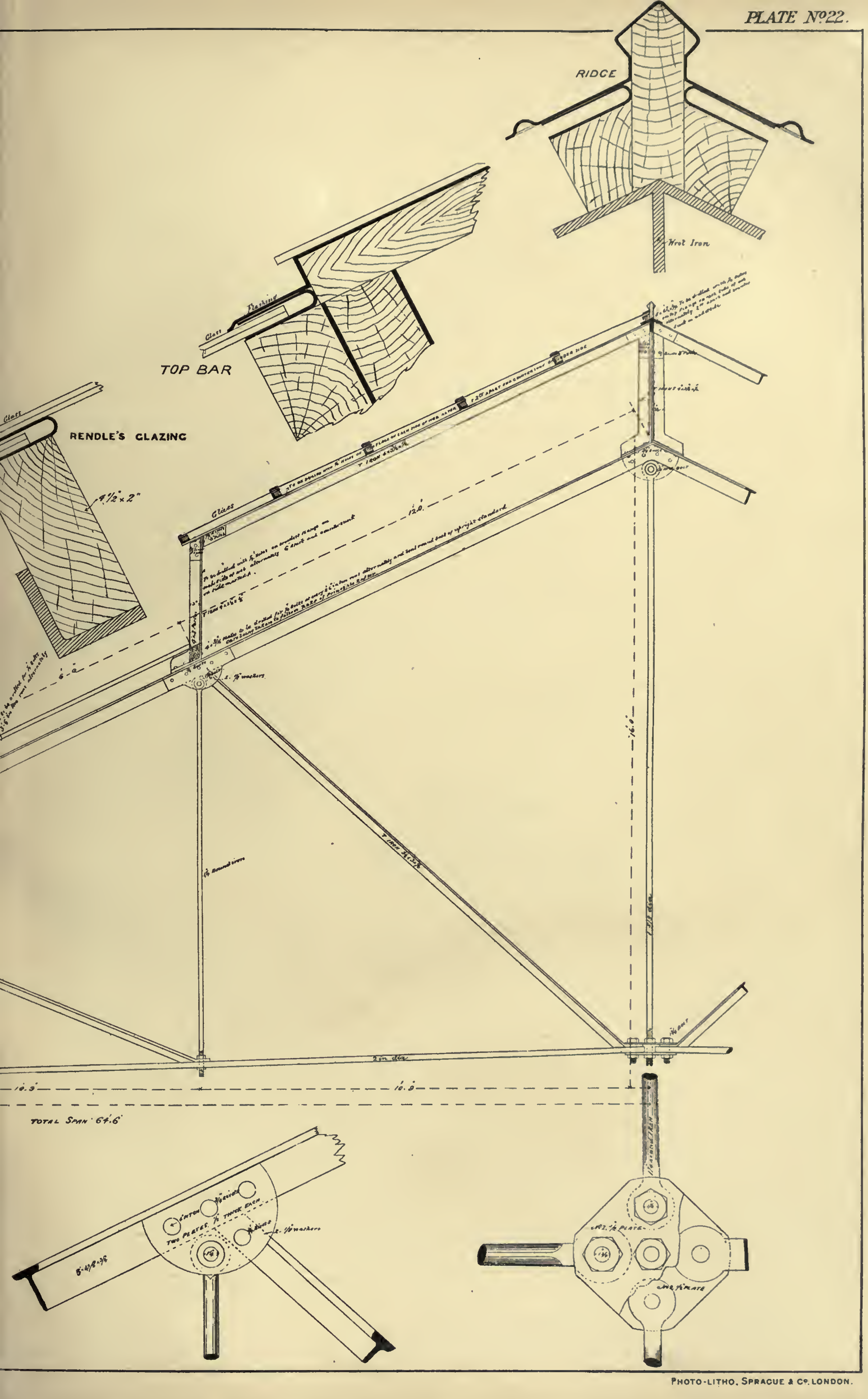
REMARKS. The ridge piece extends the whole length of Roof which is 224 ft long
There will be 23 principals, placed 10 ft apart from centre to centre, two of which will be made without Louvre portion.



SCALE OF DETAILS

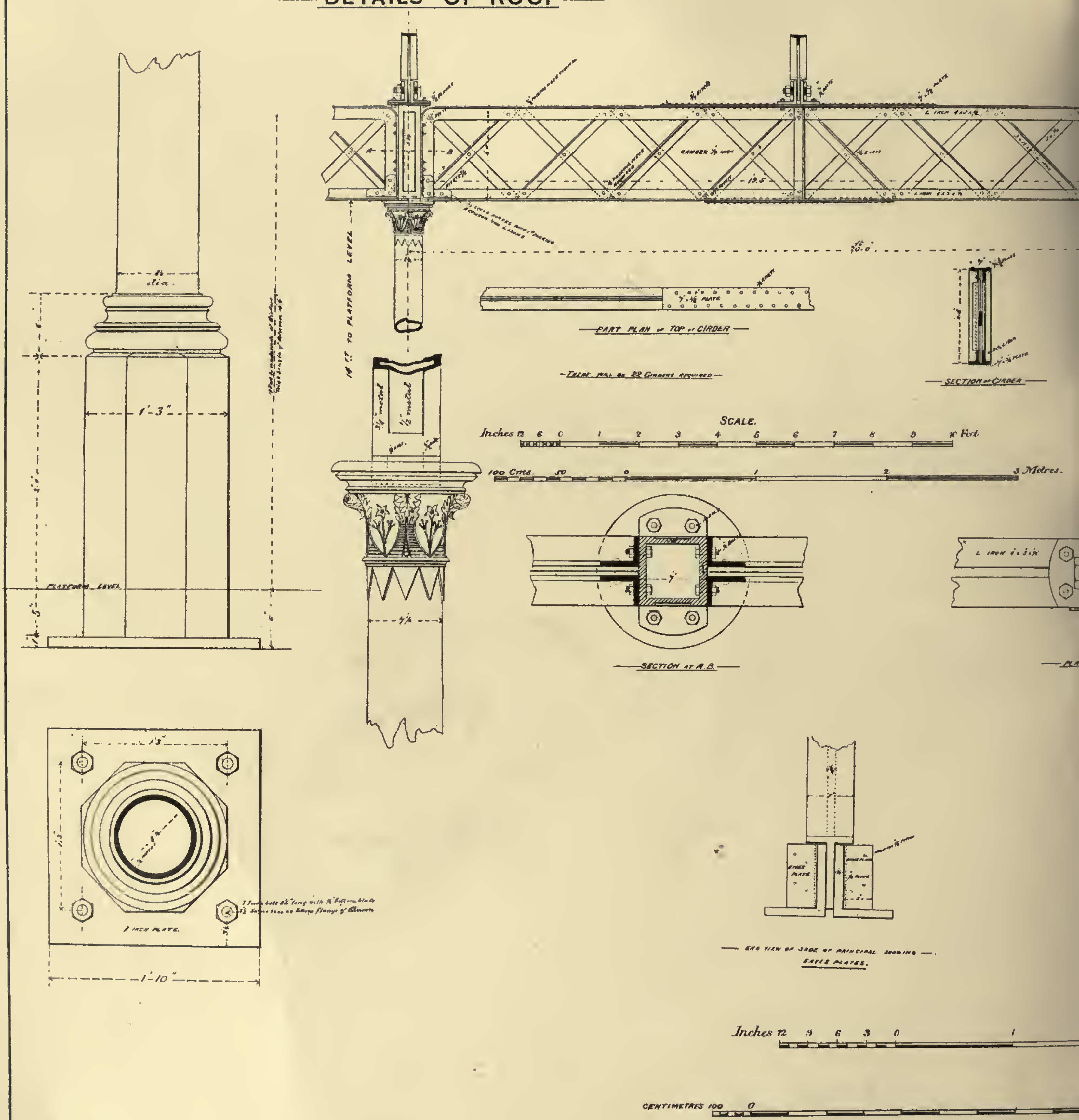
INCHES 12 9 6 3 0 1 2 3 FEET

10 0 10 20 30 40 50 60 70 80 90 CENTIMETRES


RIDGE
Wrot Iron
TOP BAR
Glass
Flashing
RENDLE'S GLAZING
Glass
9 1/2" x 2"
Glass
12.0
6.0
16.0
10.9
10.9
TOTAL SPAN 64.6
TWO PLATES 1/2 THICK EACH
PHOTO-LITHO, SPRAGUE & Co. LONDON.

—SWANSEA STATION—

—DETAILS OF ROOF—



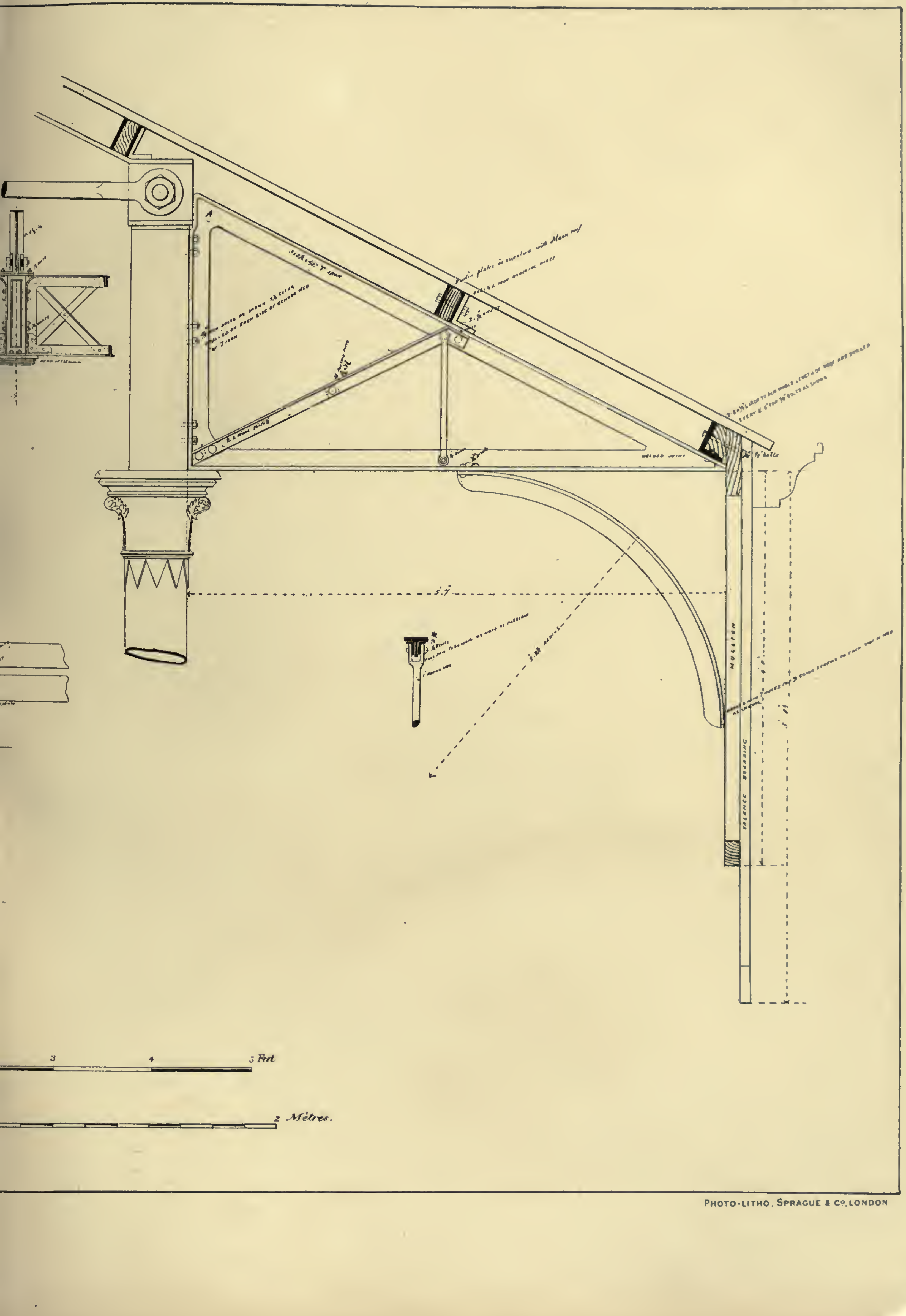
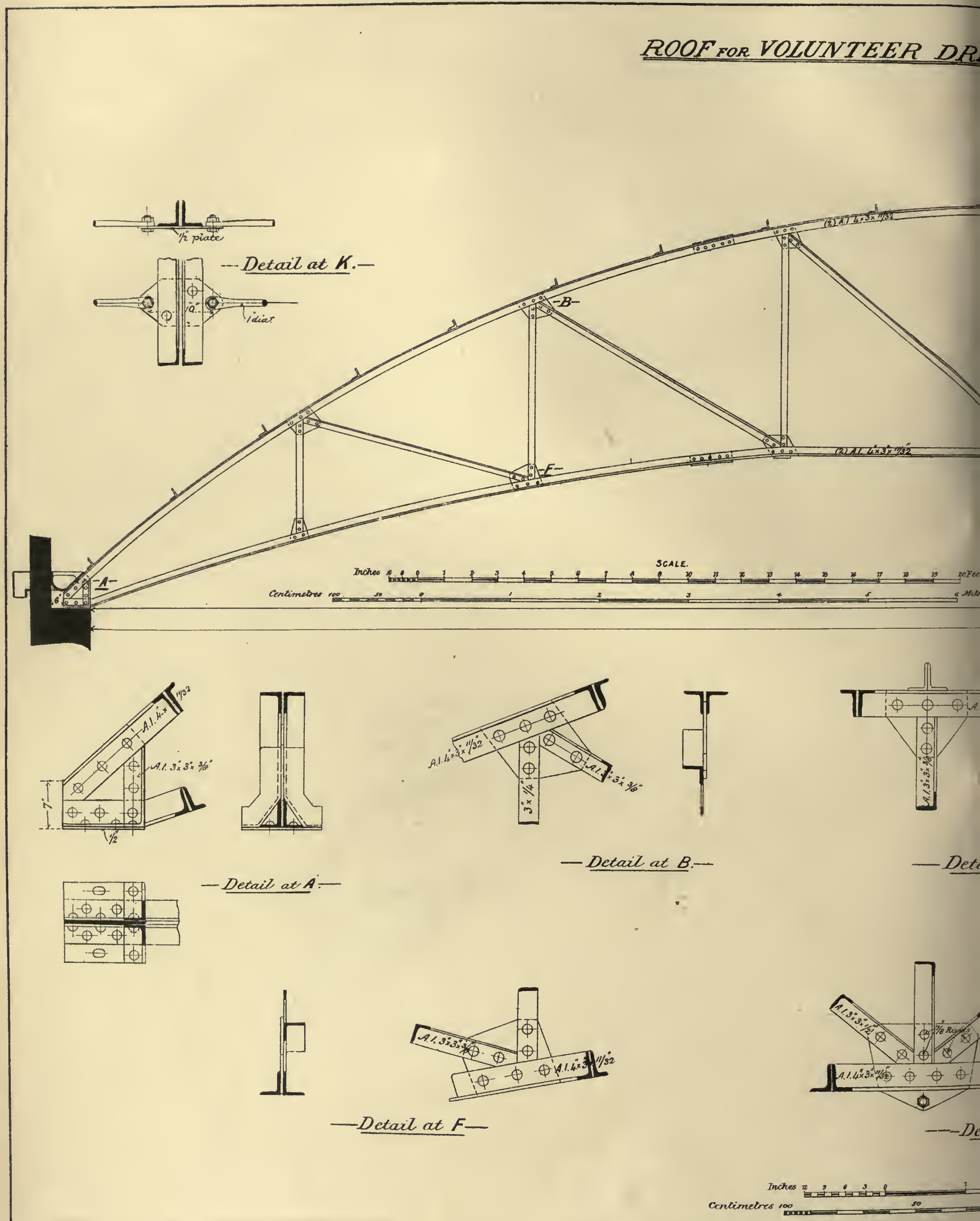


PHOTO-LITHO, SPRAGUE & Cº. LONDON


ROOF FOR VOLUNTEER DR
½" plate
Detail at K.
1" diar.
(2) A.I. 4"×3"× 11/32
-B-
-F-
-A-
SCALE.
Inches
Centimetres
Detail at A.
A.I. 4"×
11/32
A.I. 3"×3"× 3/8"
7"
½
A.I. 4"×3"× 11/32
3"× ¼
A.I. 3"×3"× 3/8"
Detail at B.
A.I. 3"×3"× 3/8
Detail at F.
A.I. 3"×3"× 3/8
A.I. 4"×3" 11/32
A.I. 3"×3"× ½"
7/8 Rivets
A.I. 4"×3"× 11/32
Inches
Centimetres

...LL — PORT ELIZABETH —

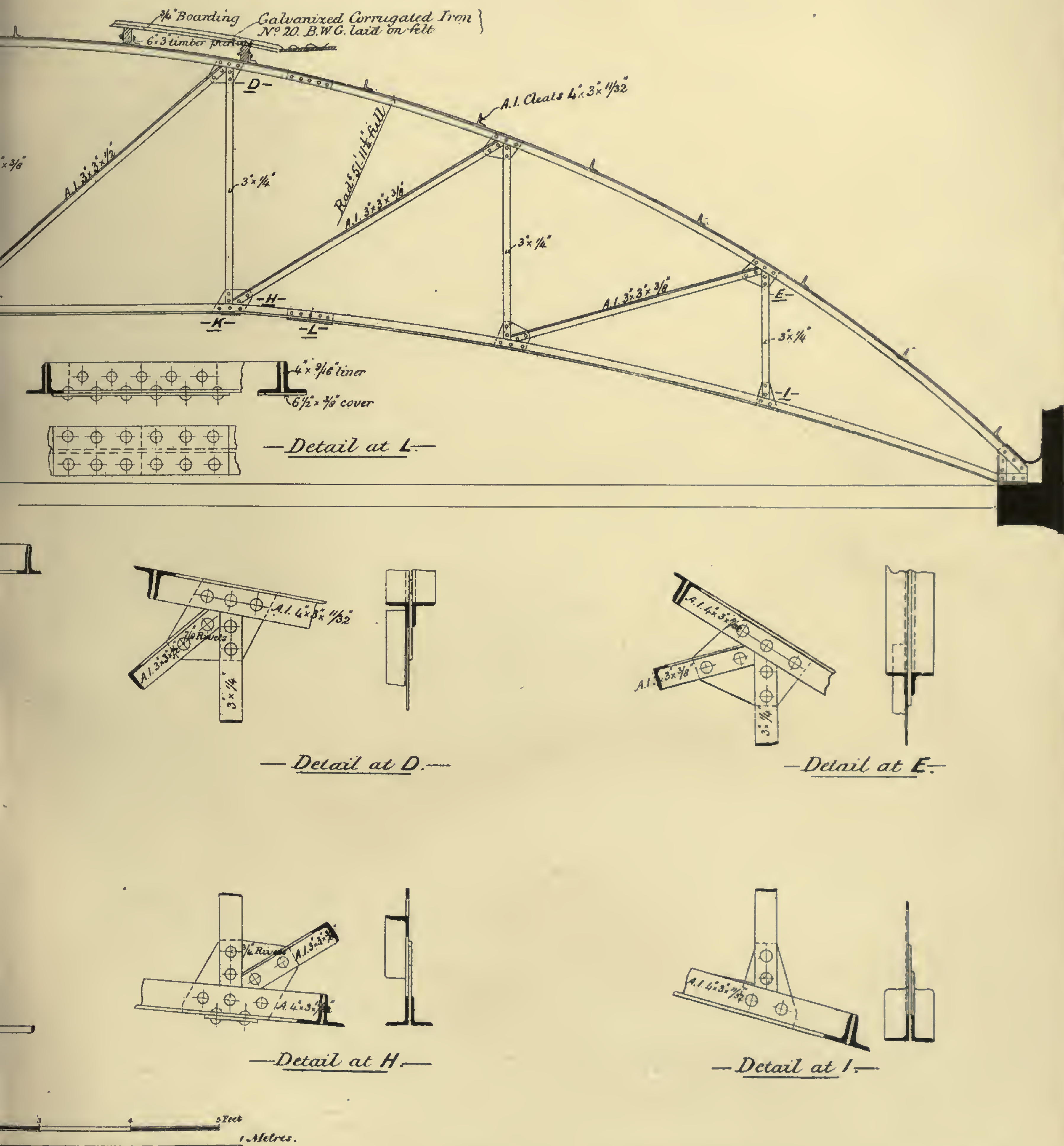
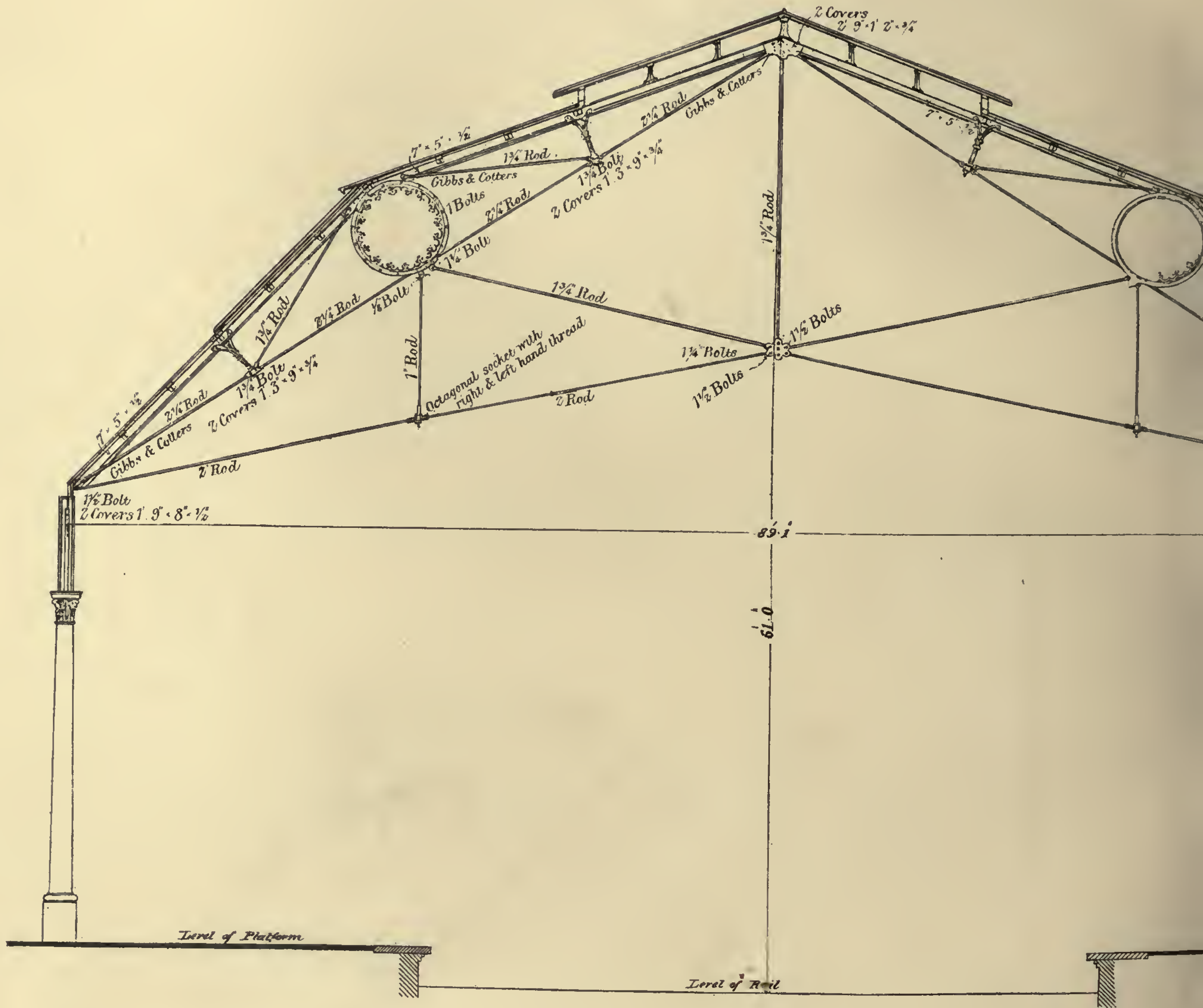


PHOTO-LITHO, SPRAGUE & Co. LONDON

—N. E & L & N. W. R—

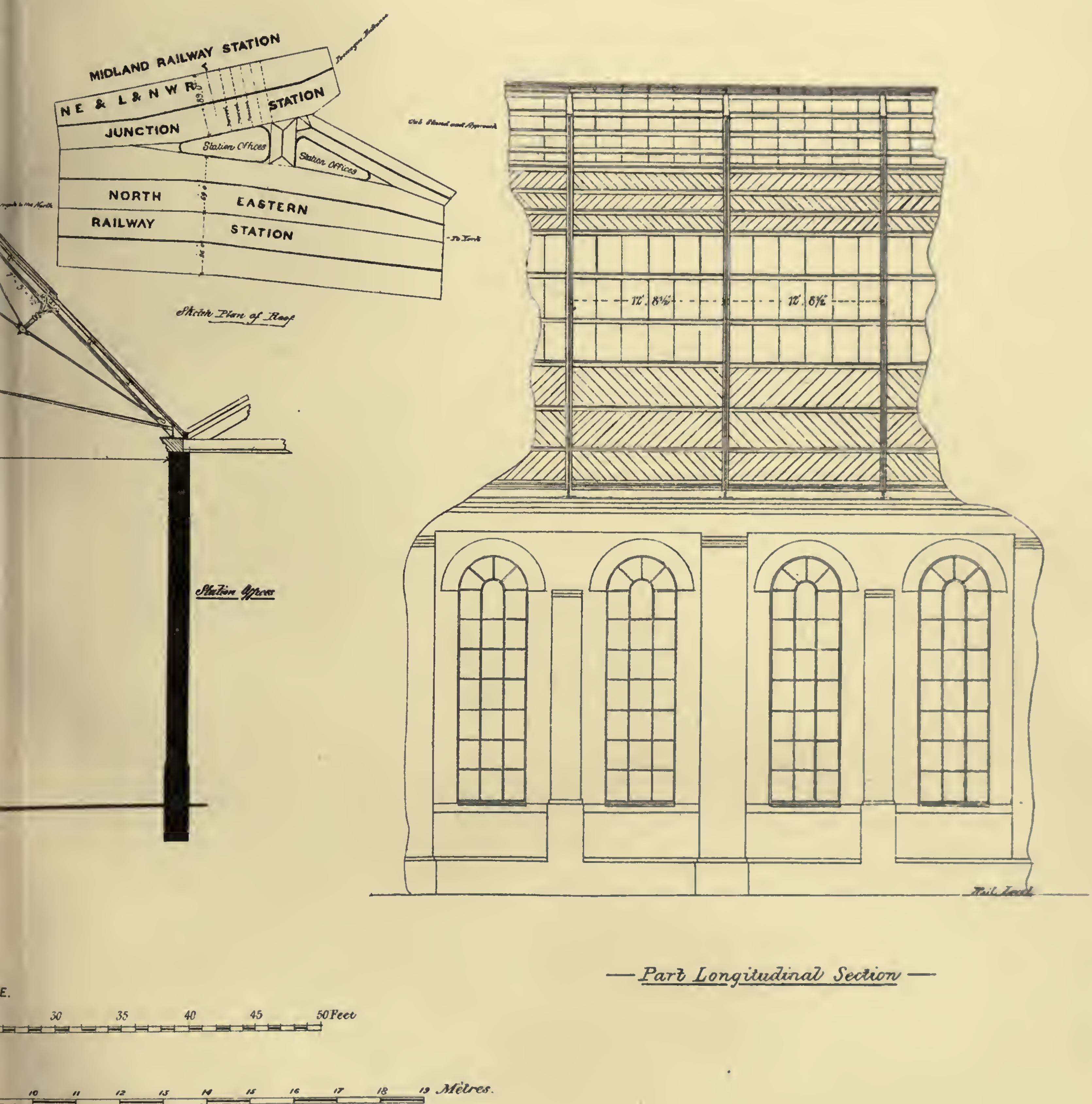
LEEDS RAILWAY STATION.



— Part Transverse Section —

Inches 12 0 1 2 3 4 5 6 7 8 9 10 15 20

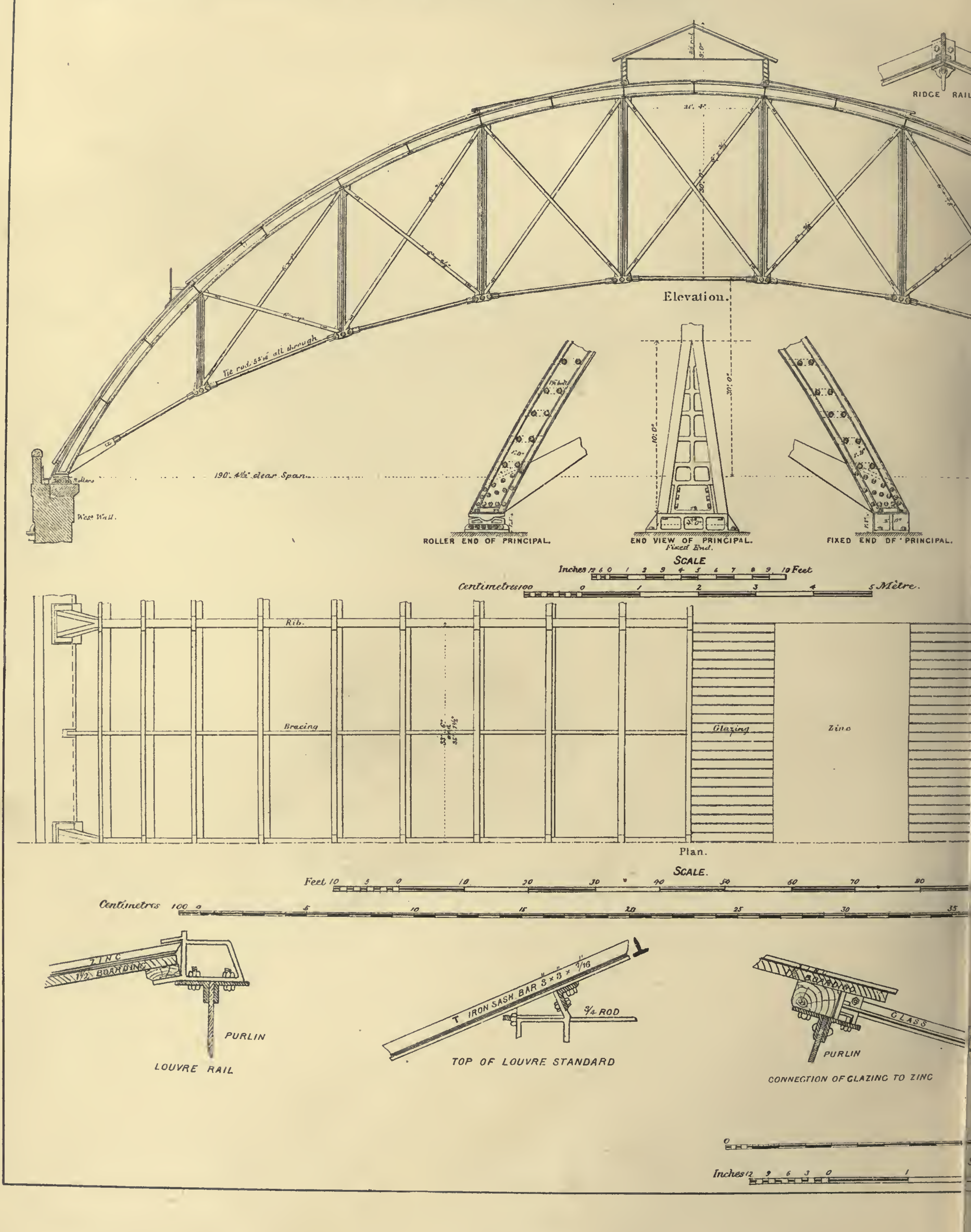
Centimetres 100 0 1 2 3 4 5 6 7



— Part Longitudinal Section —

PHOTO-LITHO. SPRAGUE & Co. LONDON

CANNON STREET STATION . S.E.R.



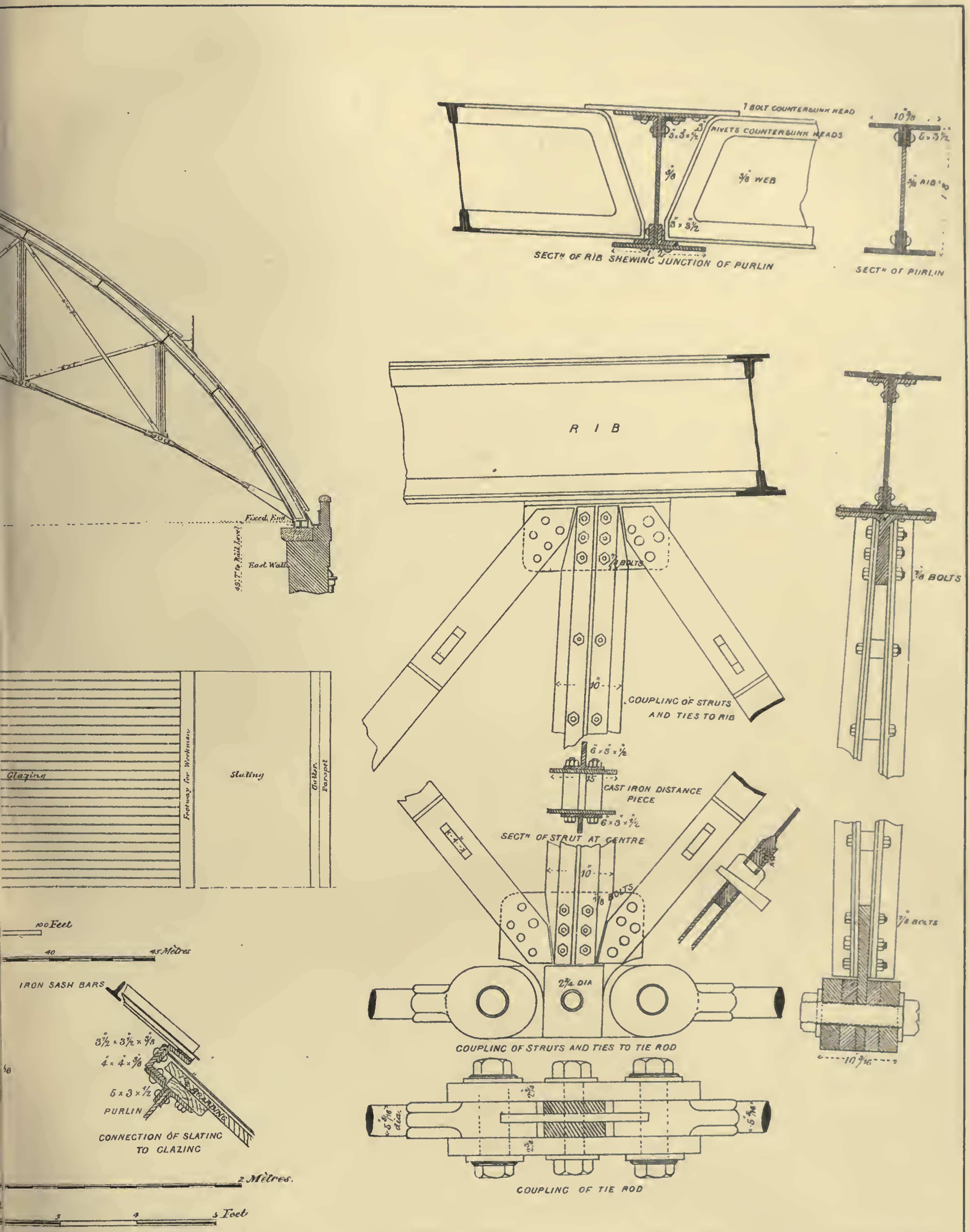
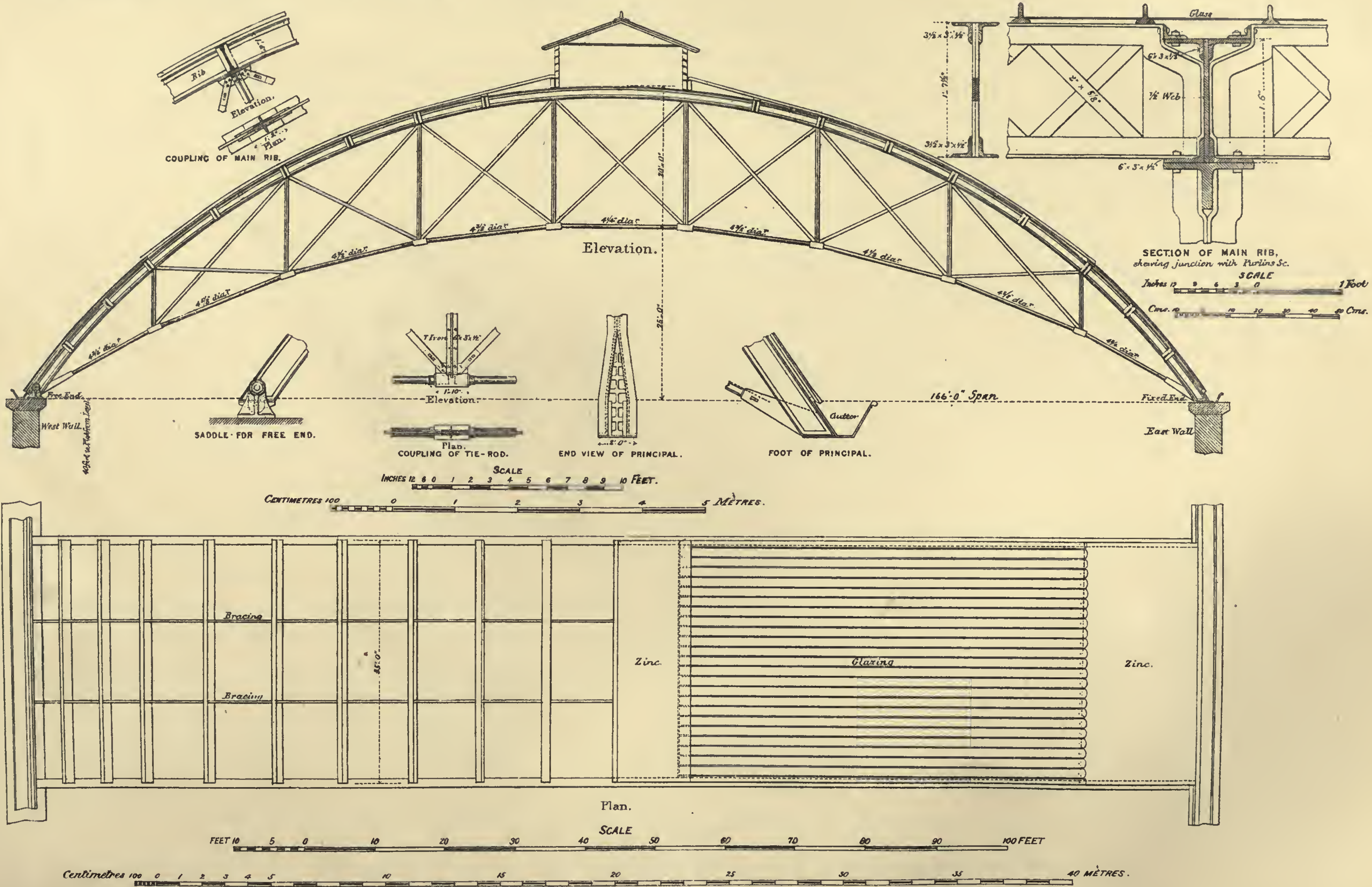
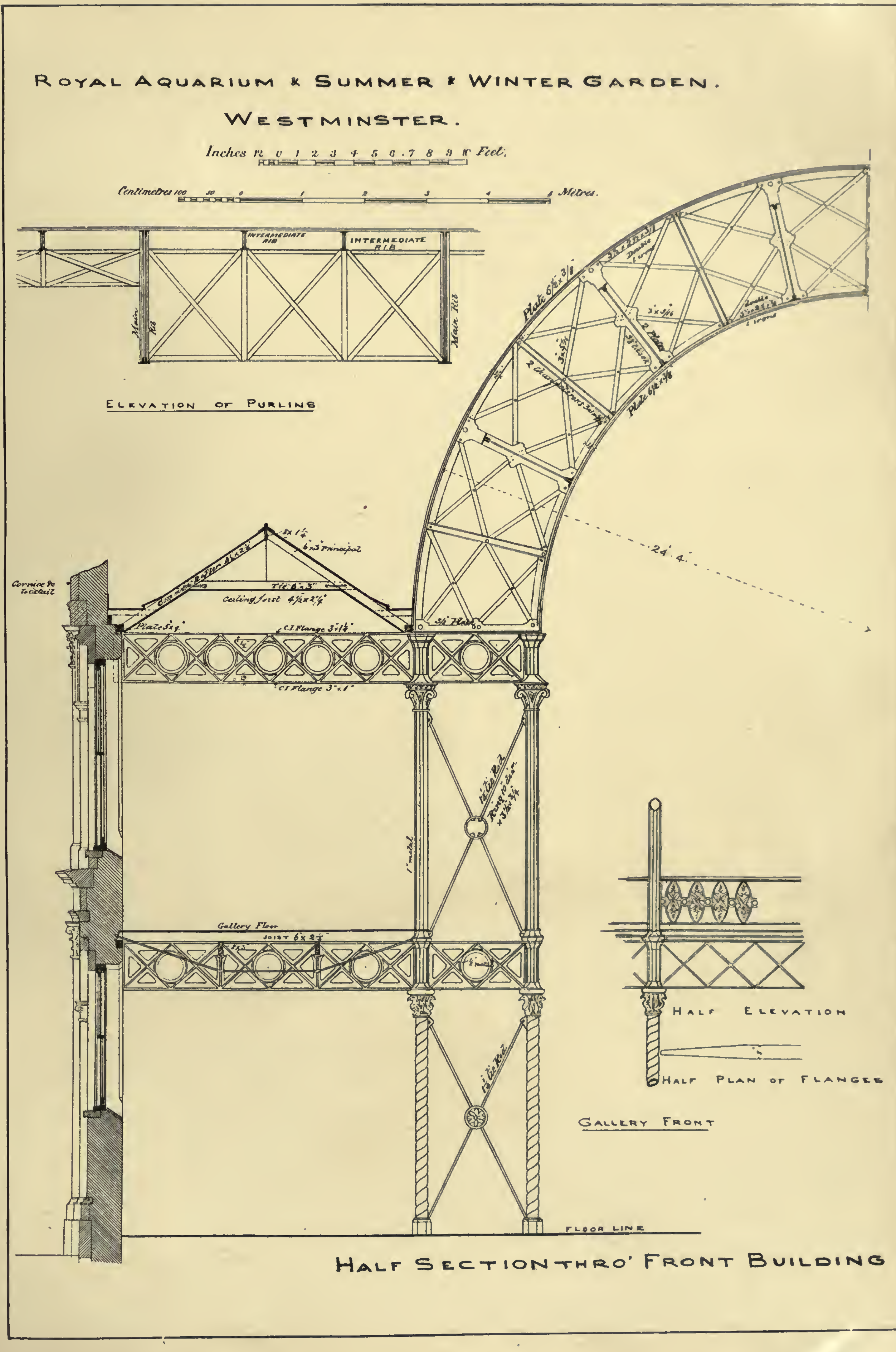


PHOTO-LITHO SPRAGUE & Co LONDON

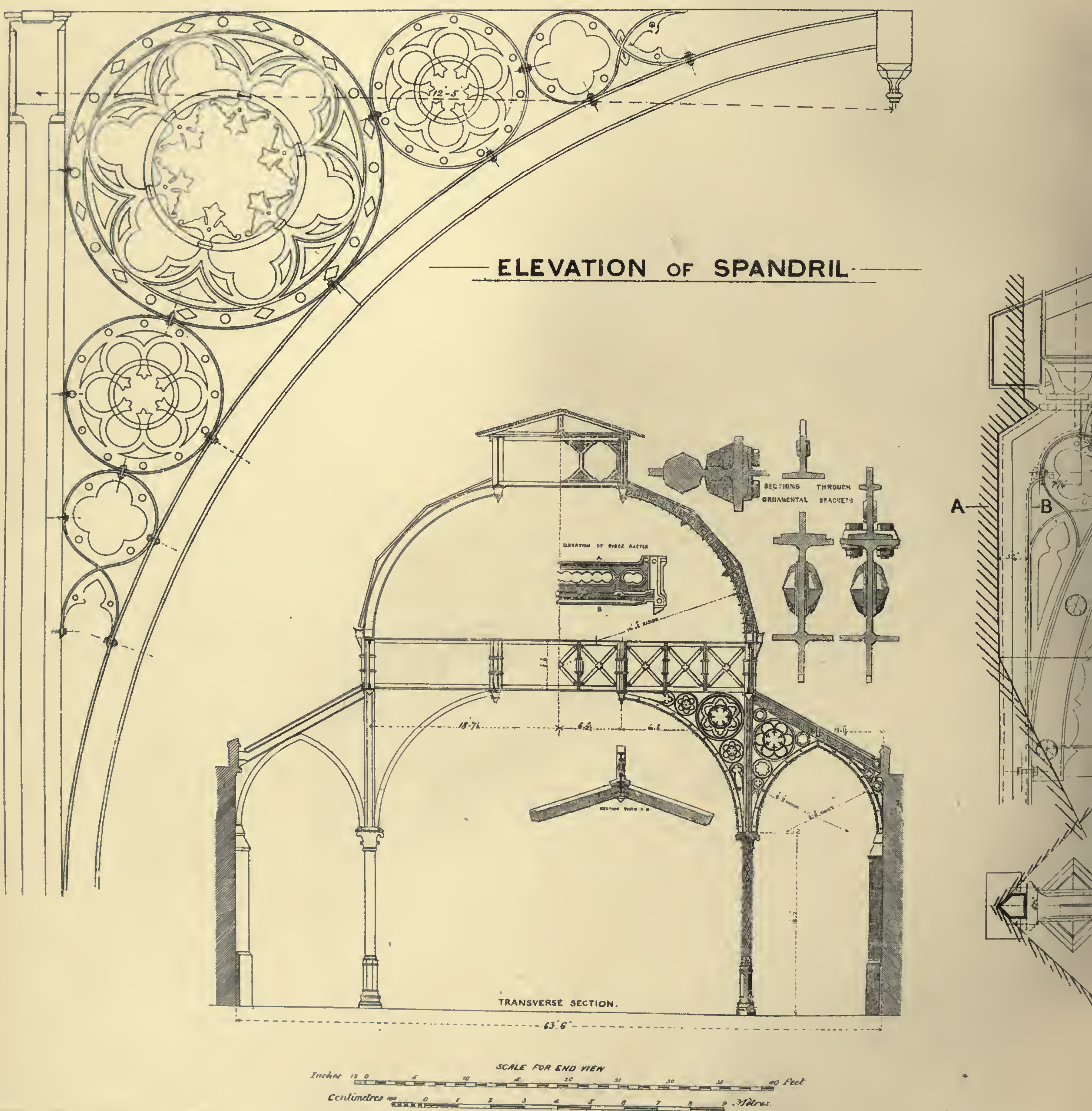
CHARING-CROSS STATION. S.E.R.




ROYAL AQUARIUM & SUMMER & WINTER GARDEN.
WESTMINSTER.
Inches 12 0 1 2 3 4 5 6 7 8 9 10 Feet.
Centimetres 100 50 0 1 2 3 4 5 Metres.
INTERMEDIATE RIB
INTERMEDIATE RIB
Main Rib
Main Rib
ELEVATION OF PURLINS
24' 4"
Cornice &c to detail
6 x 3 Principal
Tie 6 x 3
Ceiling Joist 4½ x 2¼
C.I. Flange 3 x 1¼
C.I. Flange 3 x 1
Gallery Floor
JOIST 6 x 2
1" metal
FLOOR LINE
HALF ELEVATION
HALF PLAN OF FLANGES
GALLERY FRONT
HALF SECTION THRO' FRONT BUILDING

LEEDS EXHIBITION.

ROOF OVER THE WINTER GARDEN.



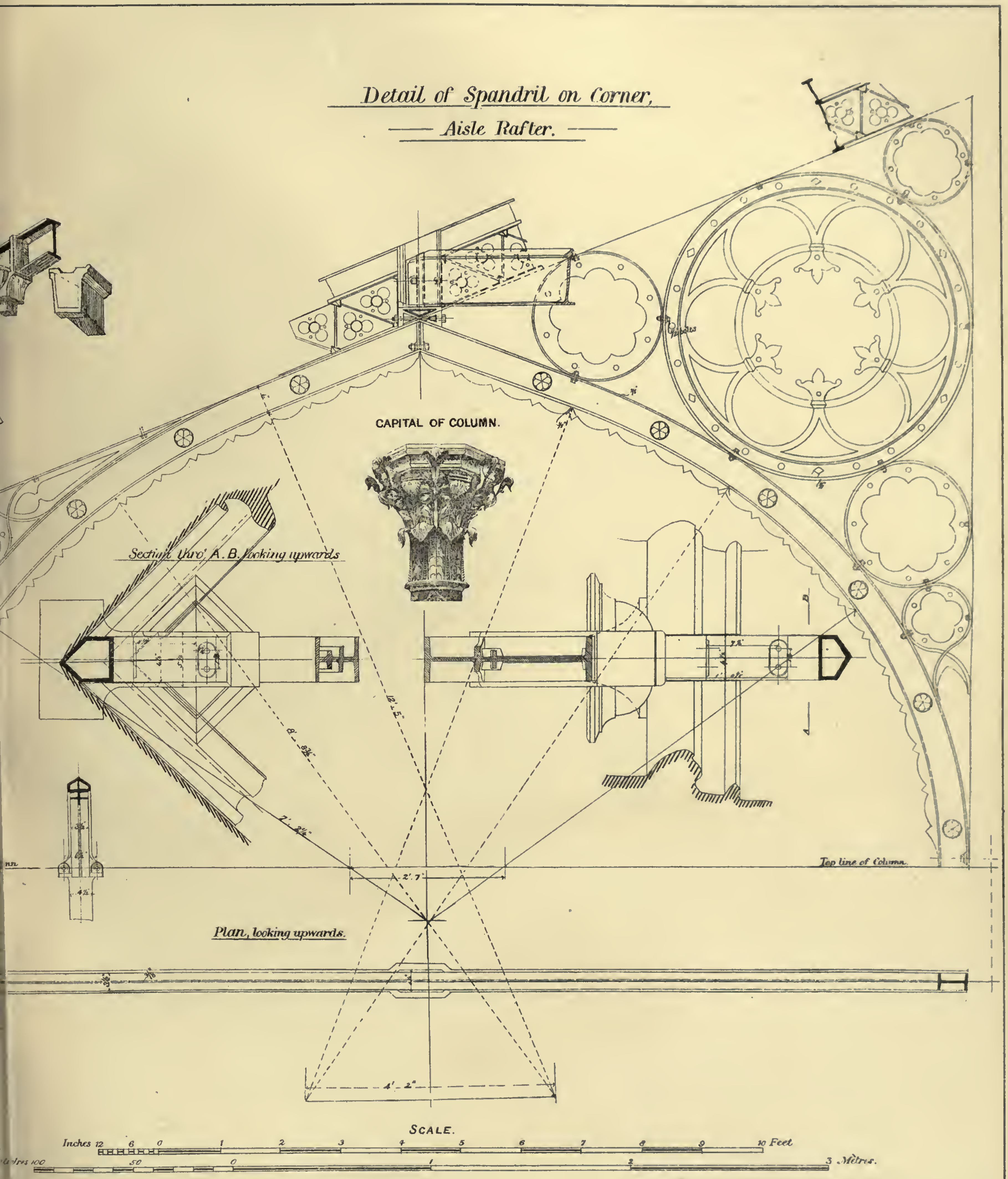
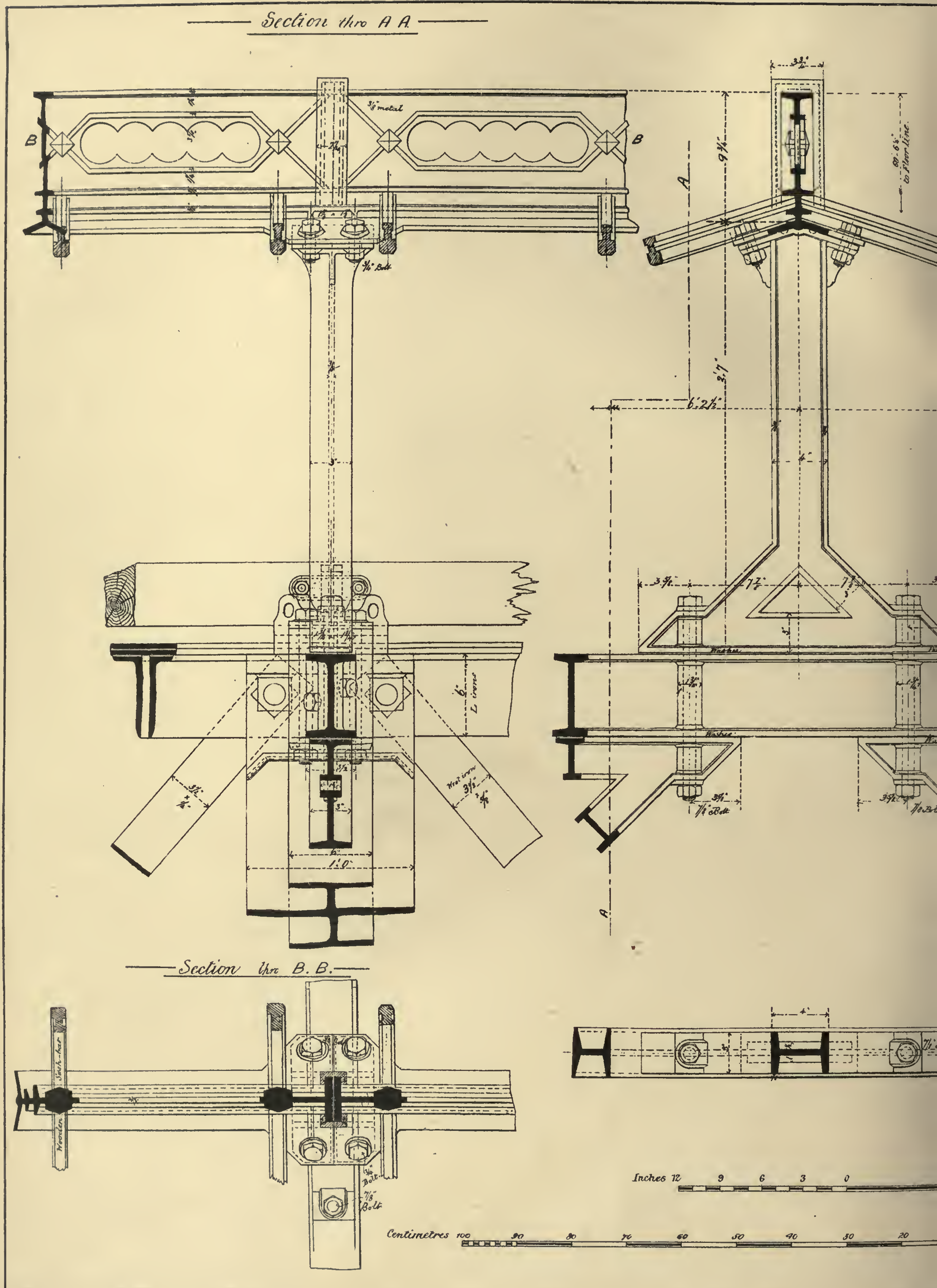


PHOTO-LITHO. SPRAGUE & Co. LONDON.



Section thro A A.
Section thro B. B.
Inches 12 9 6 3 0
Centimetres 100 90 80 70 60 50 40 30 20

LEEDS EXHIBITION.

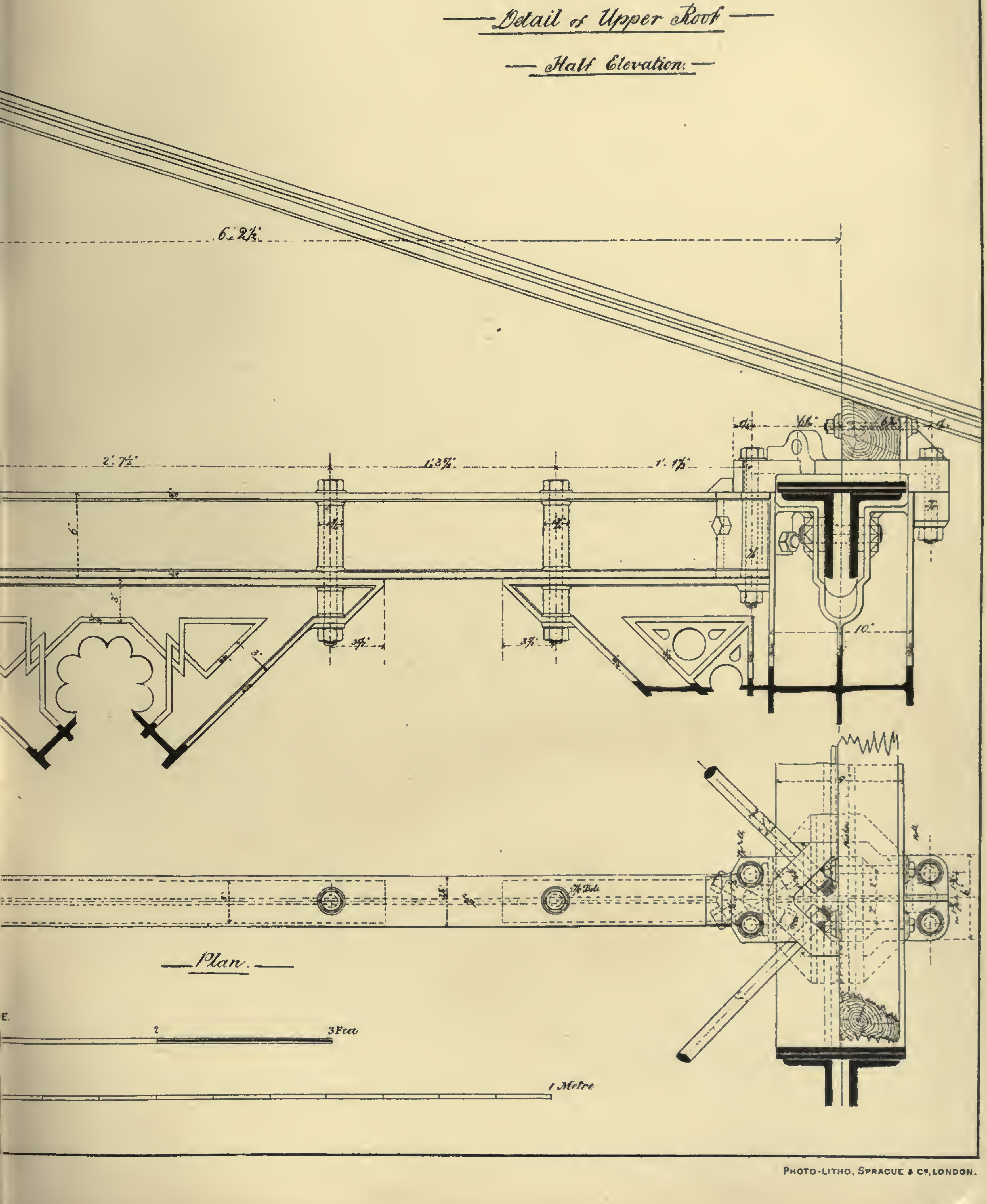
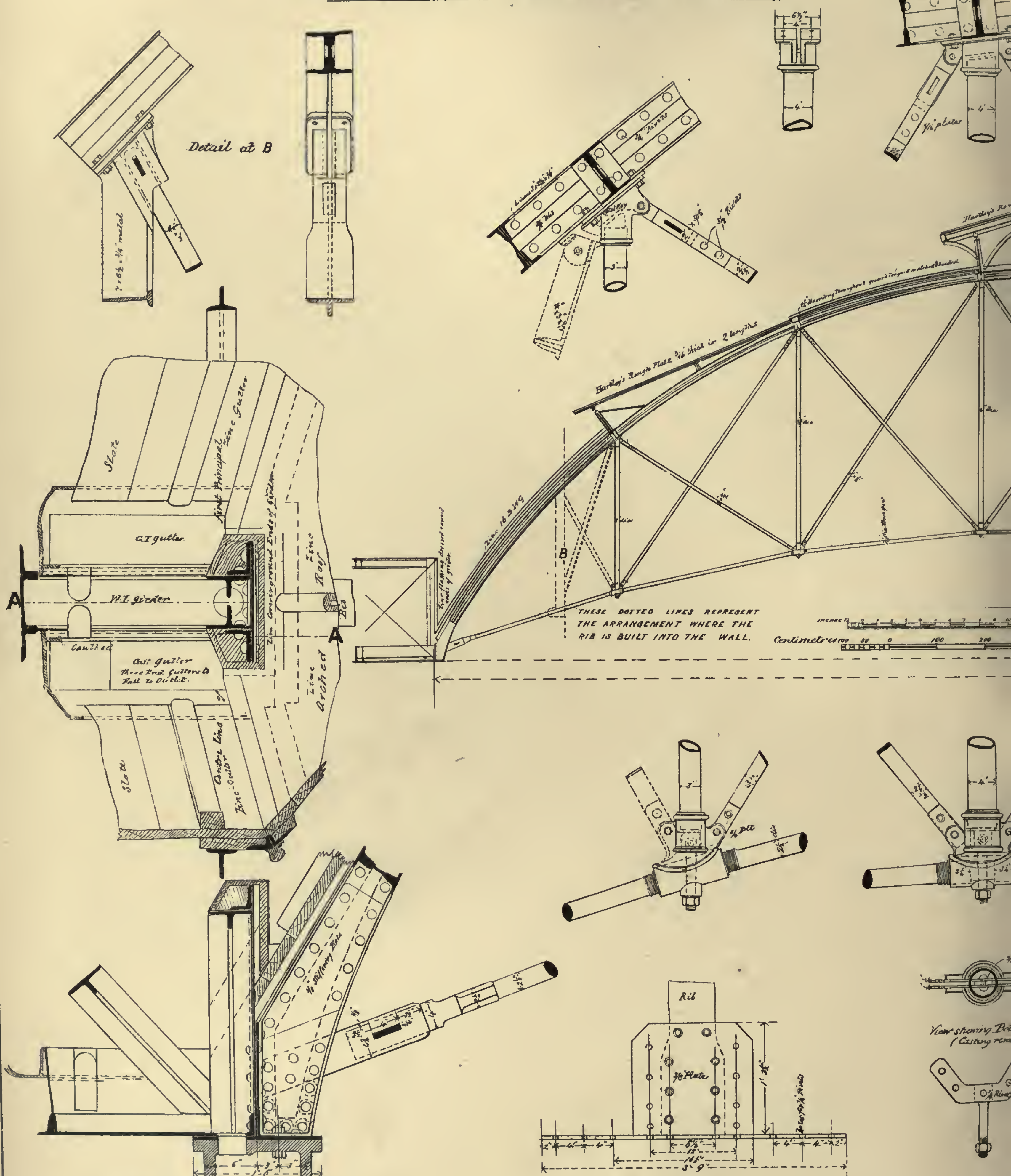


PHOTO-LITHO. SPRAGUE & Co. LONDON.

LONDON BRIDGE STATION . L B

MAIN ARCHED RIB



SECTION AA

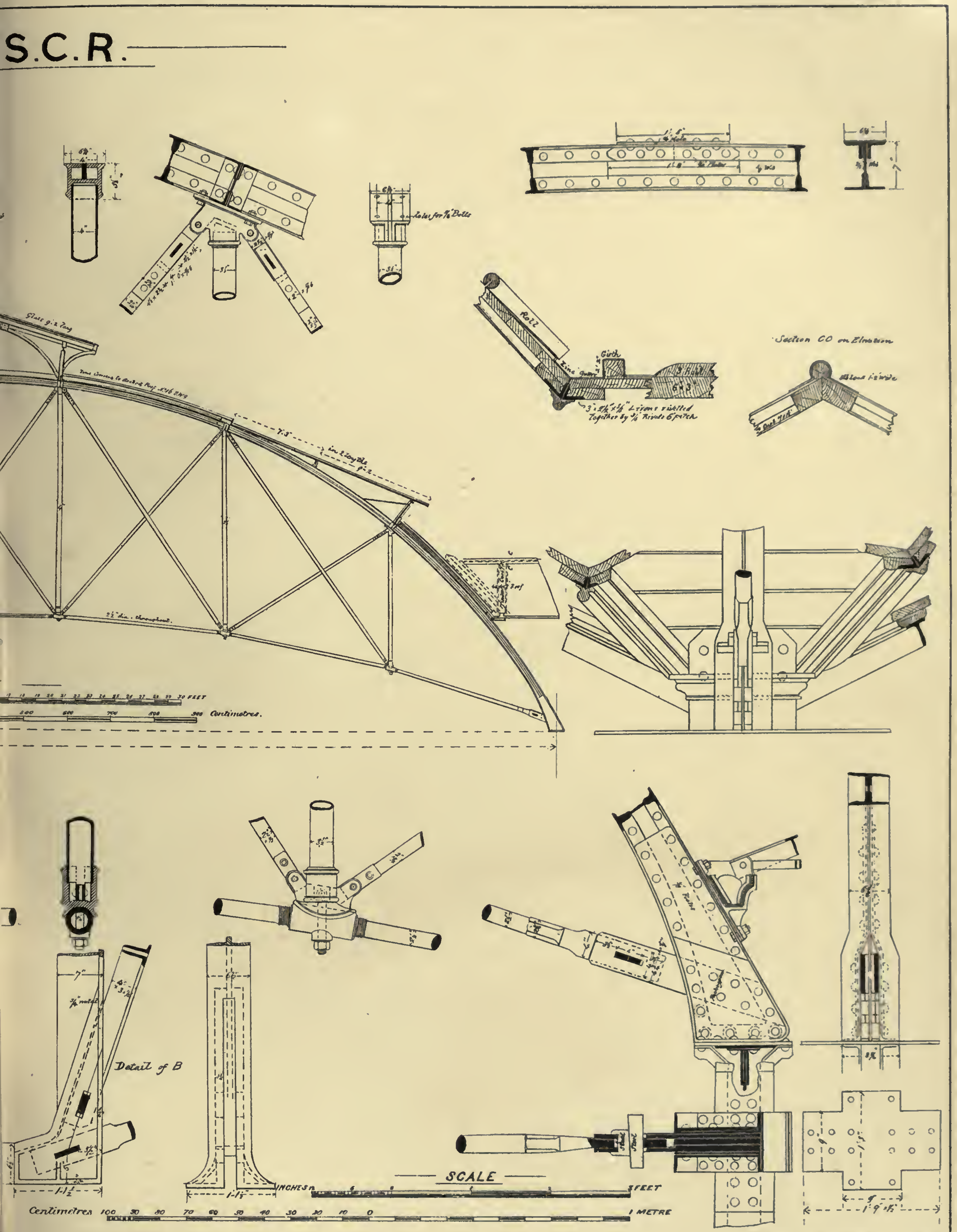
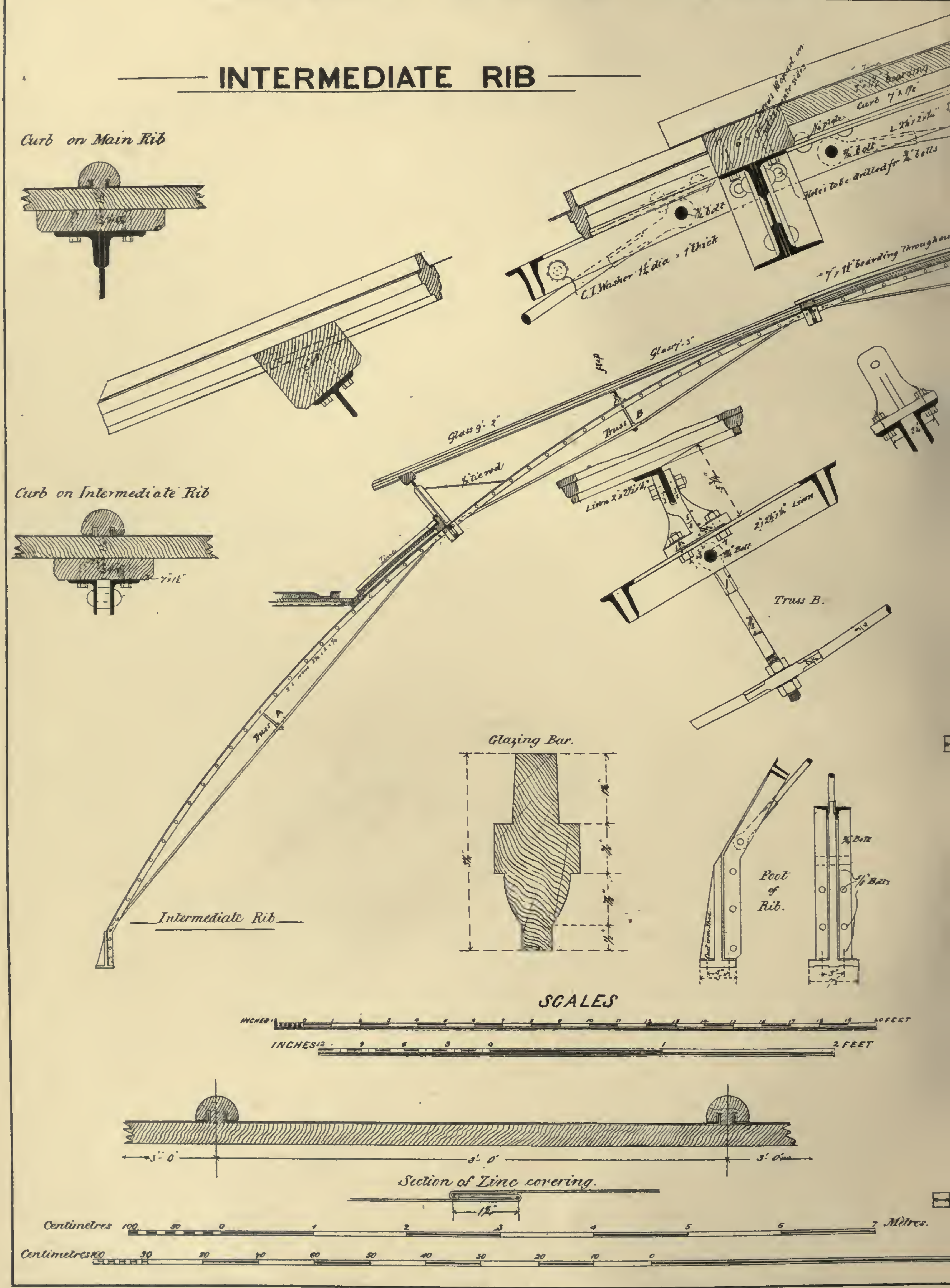


PHOTO-LITHO, SPRAGUE & Co. LONDON.

LONDON BRIDGE STATION . L B

INTERMEDIATE RIB



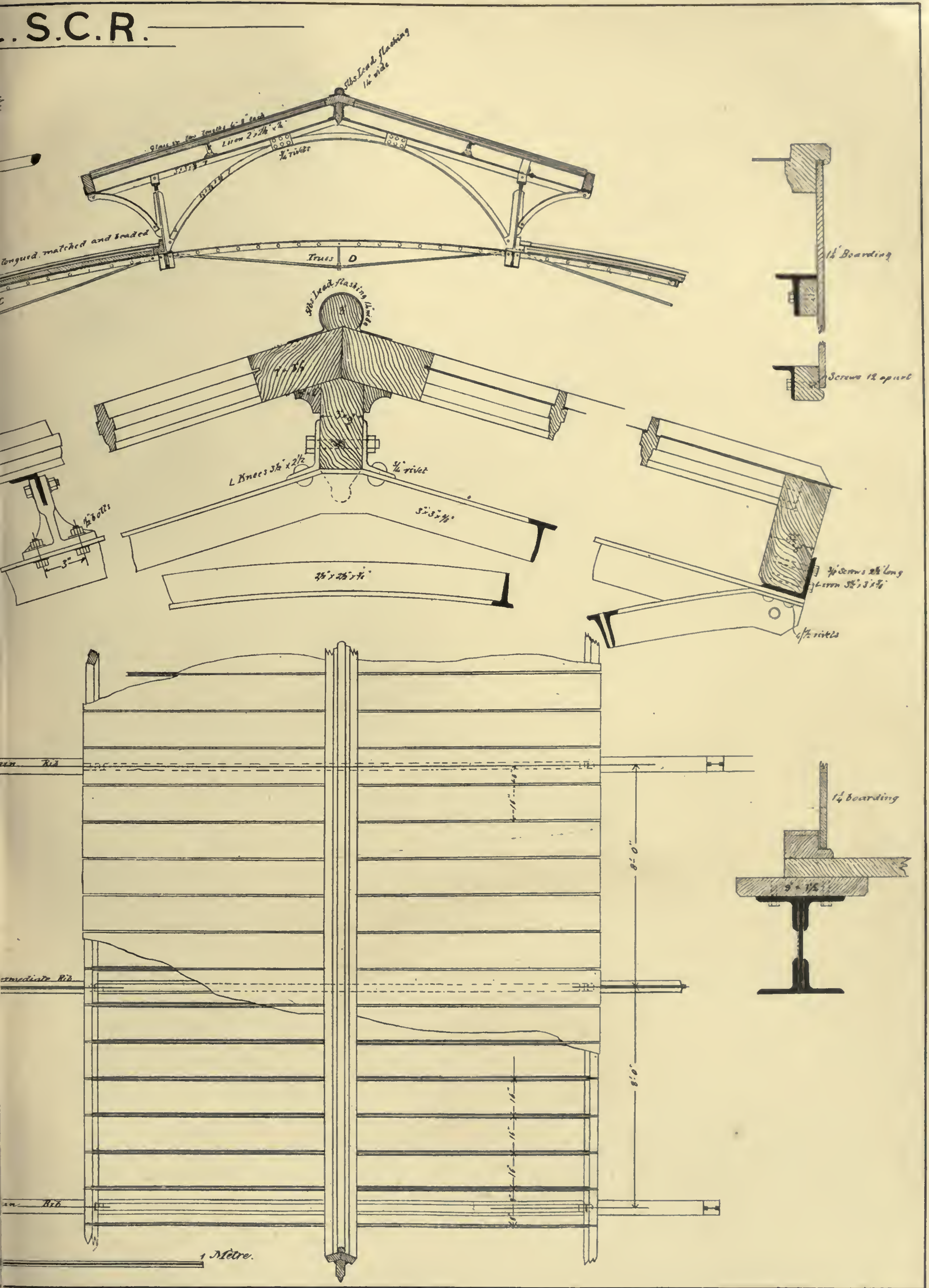
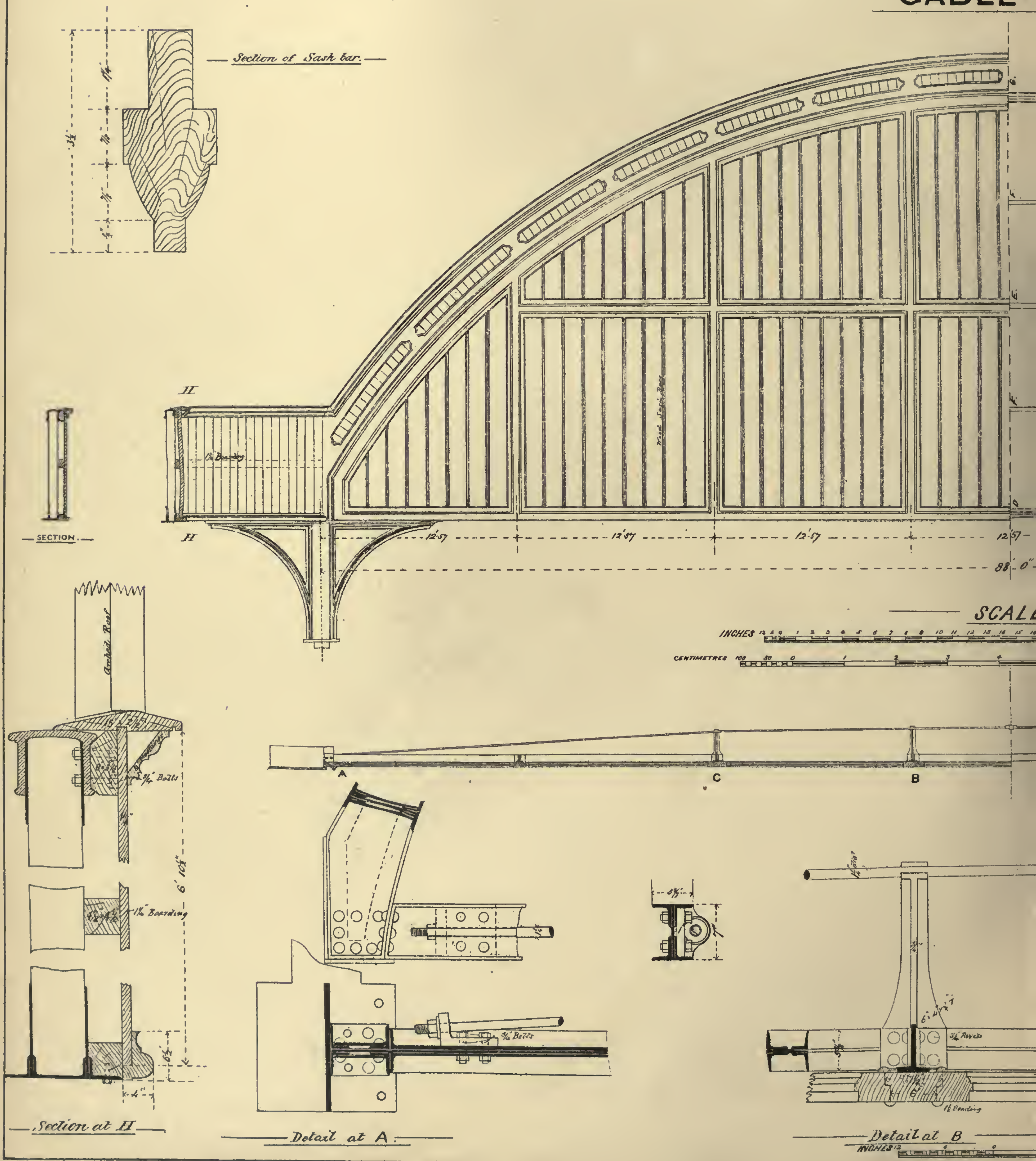


PHOTO-LITHO, SPRAGUE & Co. LONDON

LONDON BRIDGE STATION. L. B

GABLE



& S. C. R.

ND

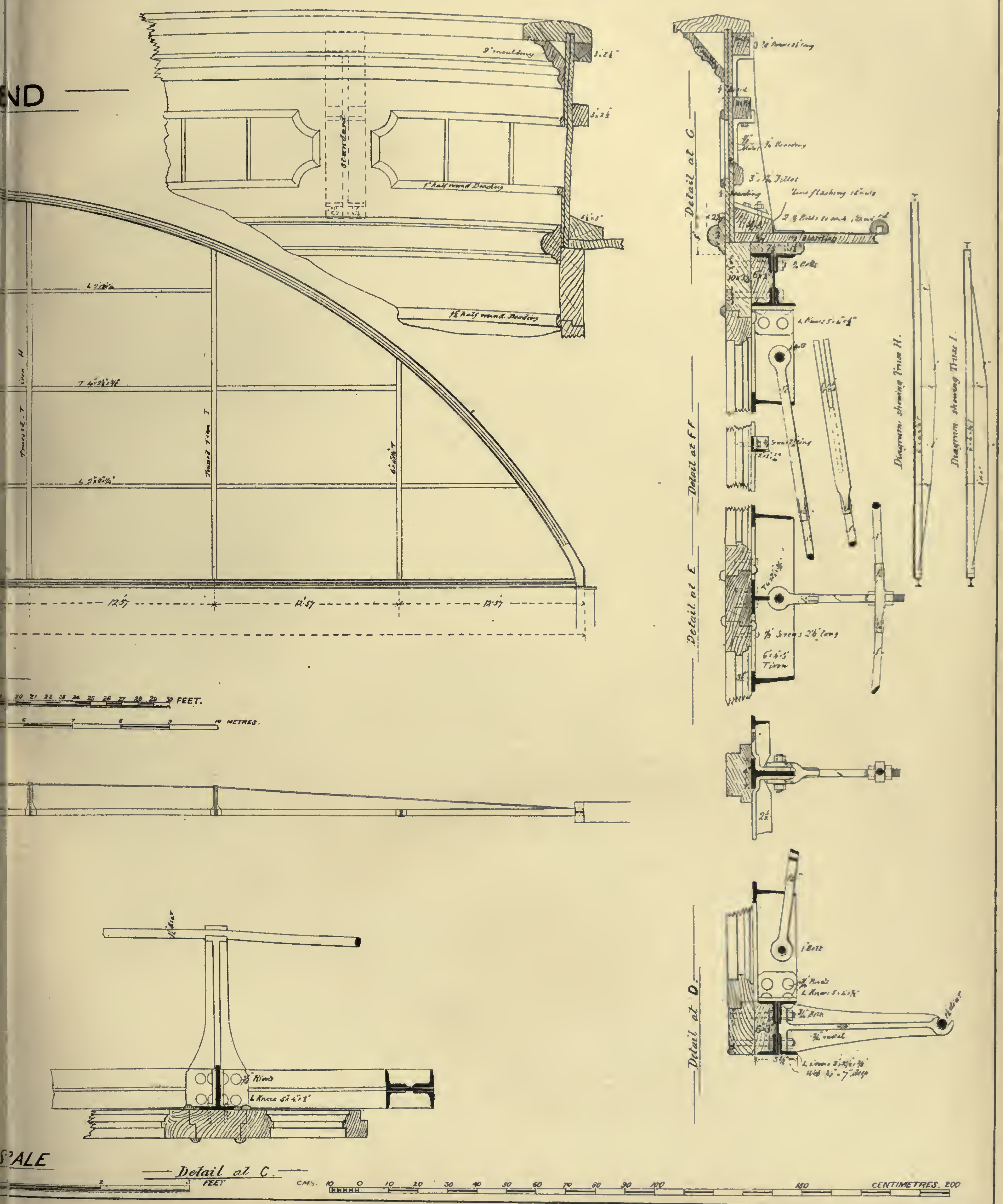
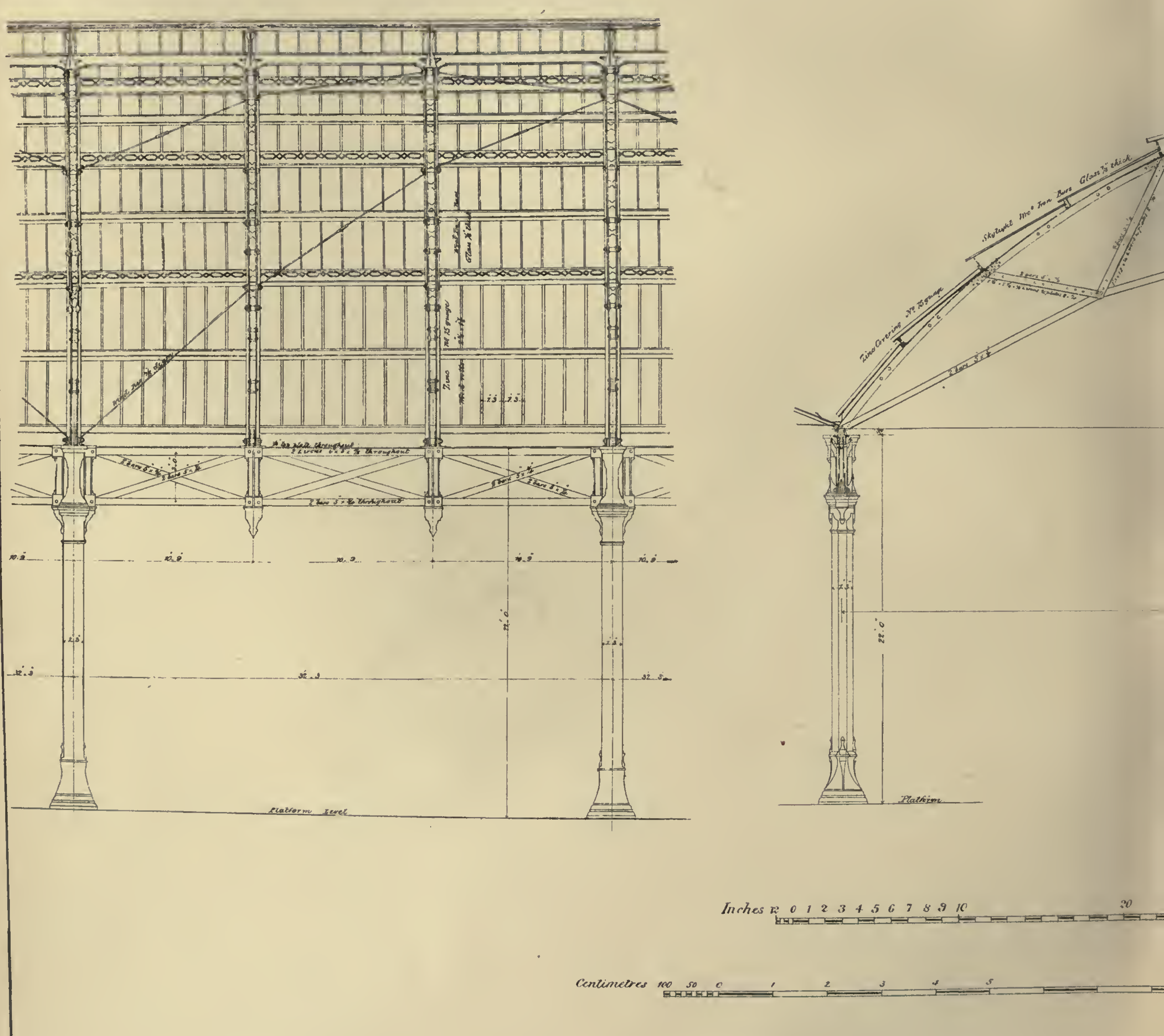


PHOTO-LITHO, SPRAGUE & Co LONDON.

BLACKFRIARS STATION. L.C & D.R.



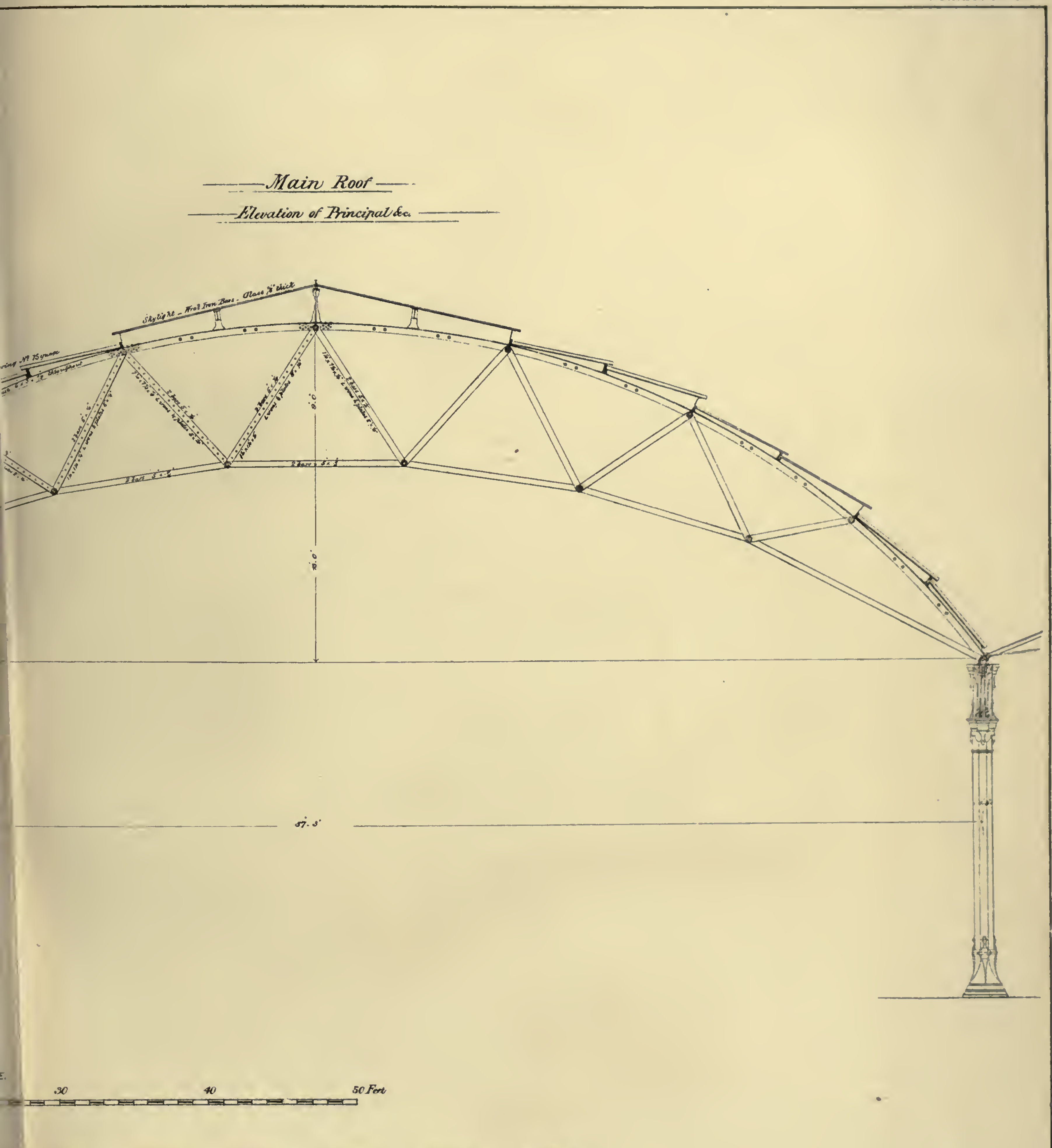
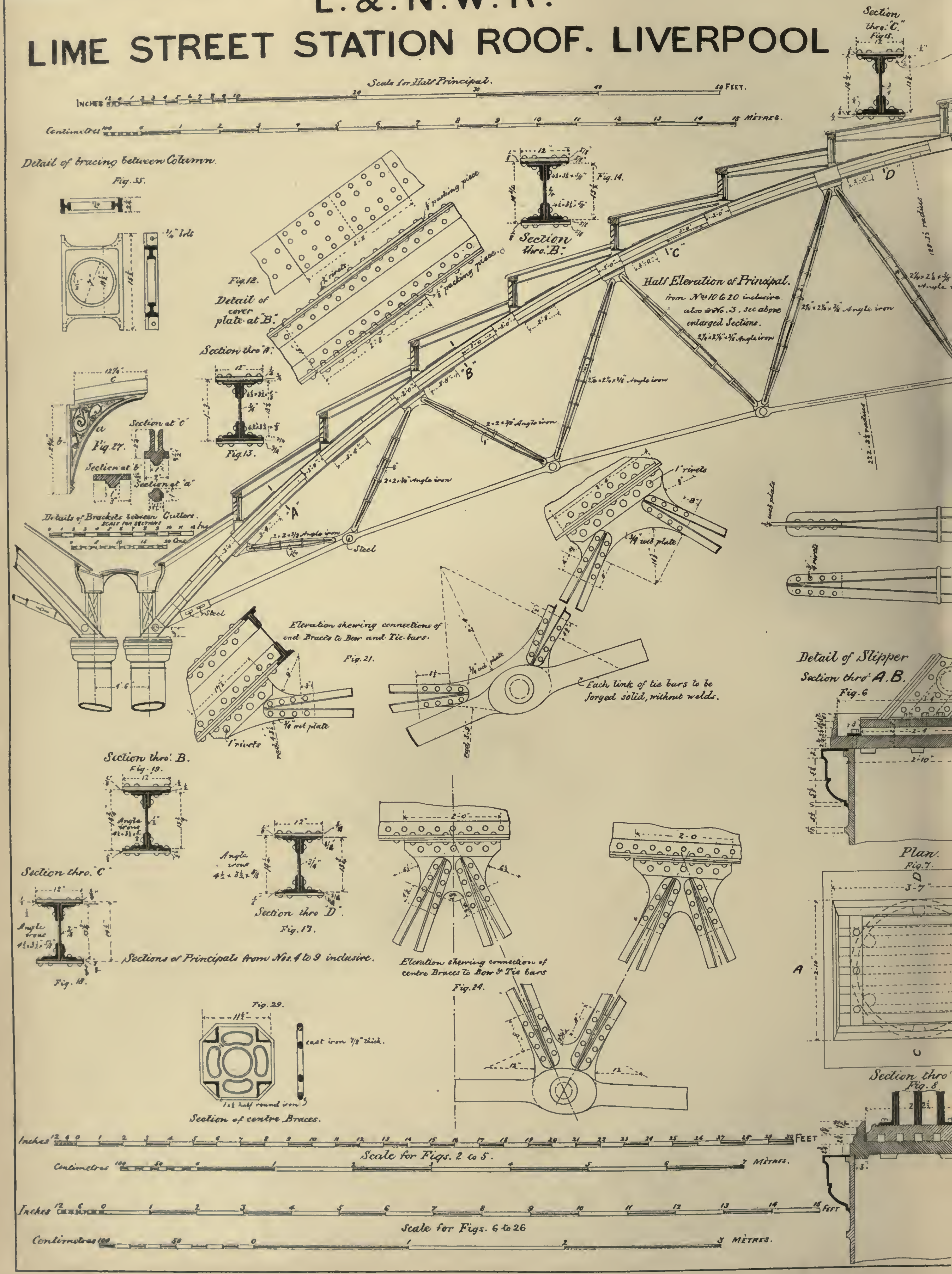


PHOTO-LITHO. SPRAGUE & Co. LONDON.

L. & N. W. R.
LIME STREET STATION ROOF. LIVERPOOL



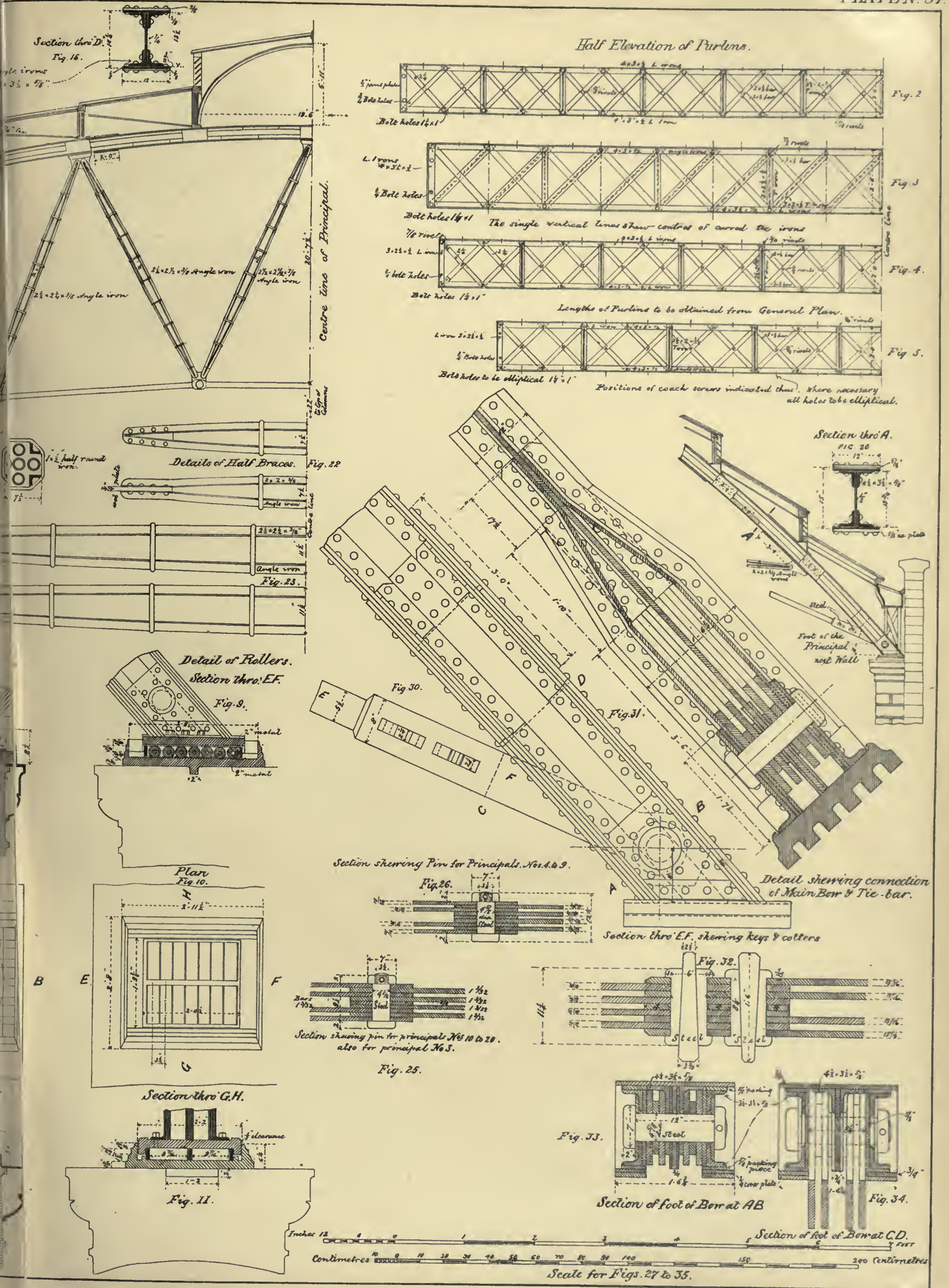
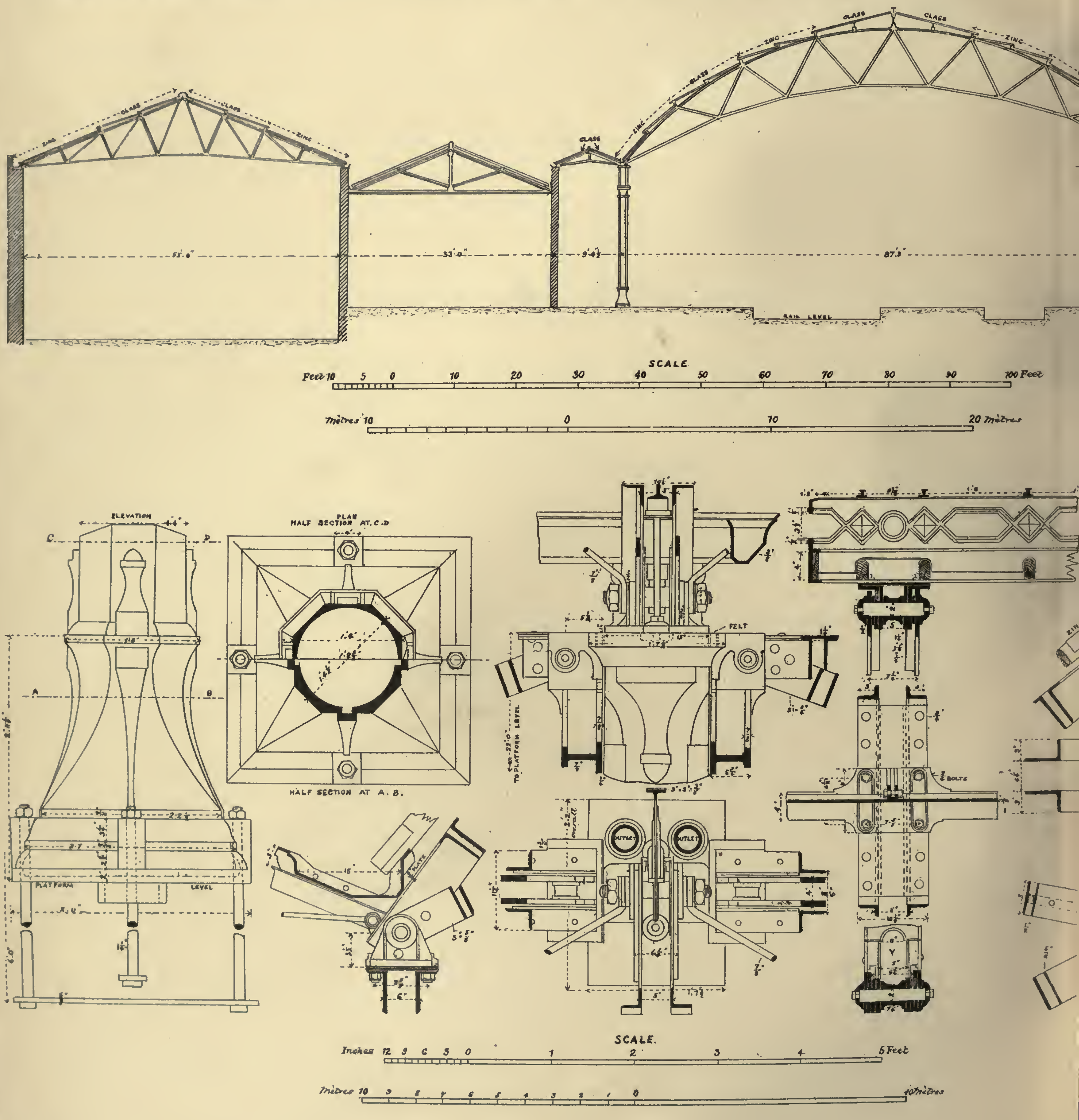


PHOTO-LITHO, SPRAGUE & Co LONDON

BLACKFRIARS STATION. L.C & D.R.



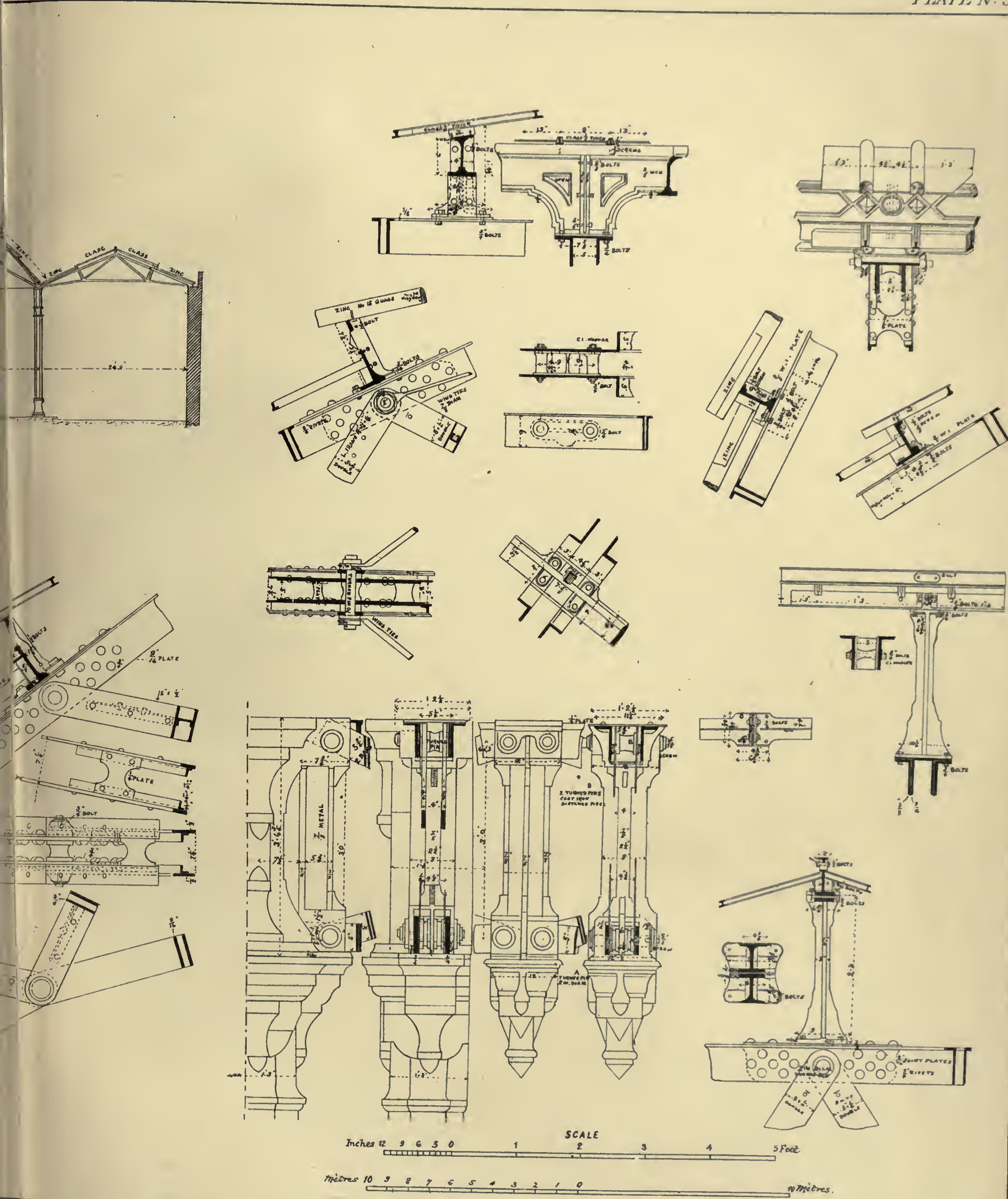
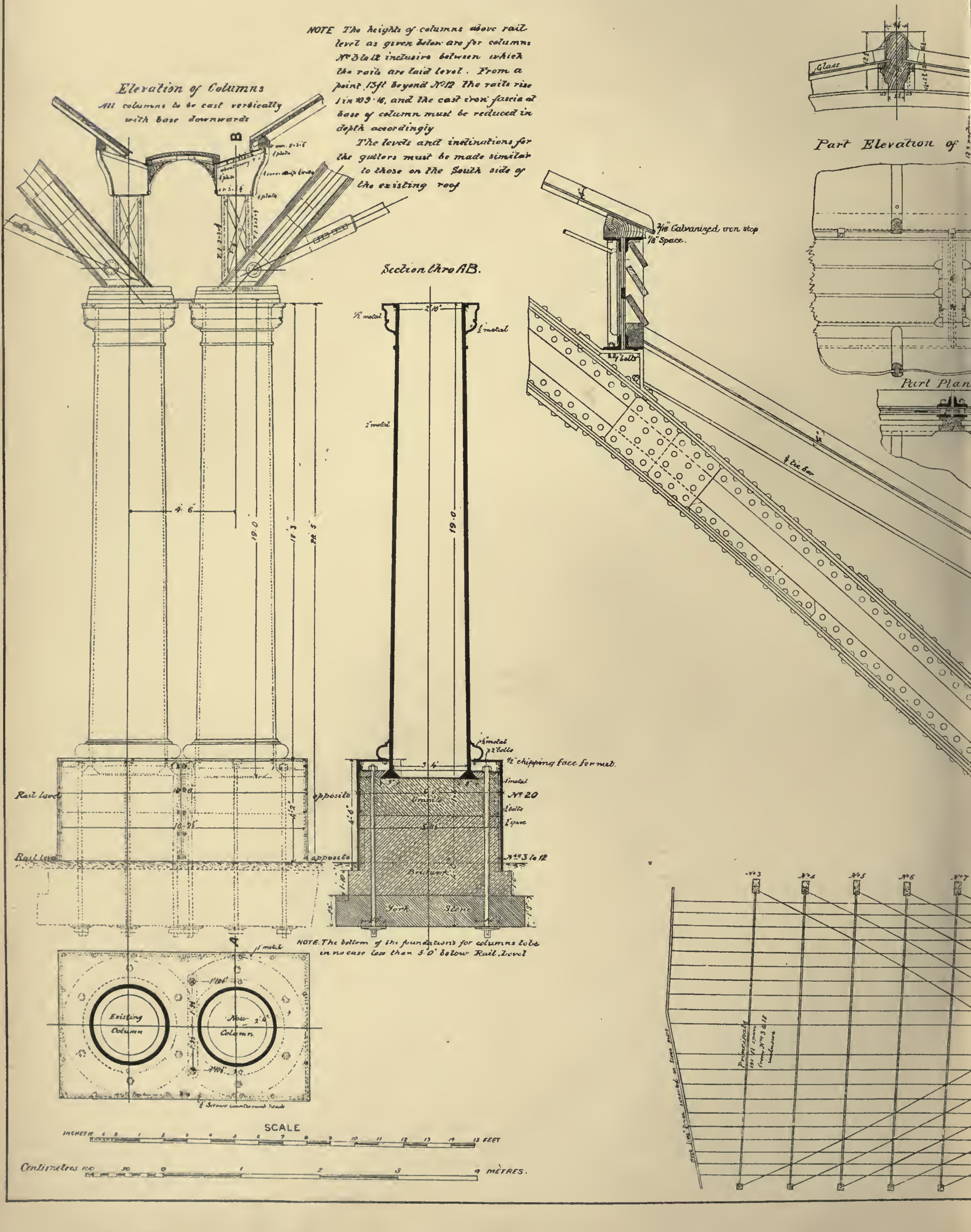


PHOTO-LITHO, SPRAGUE & Cº LONDON.

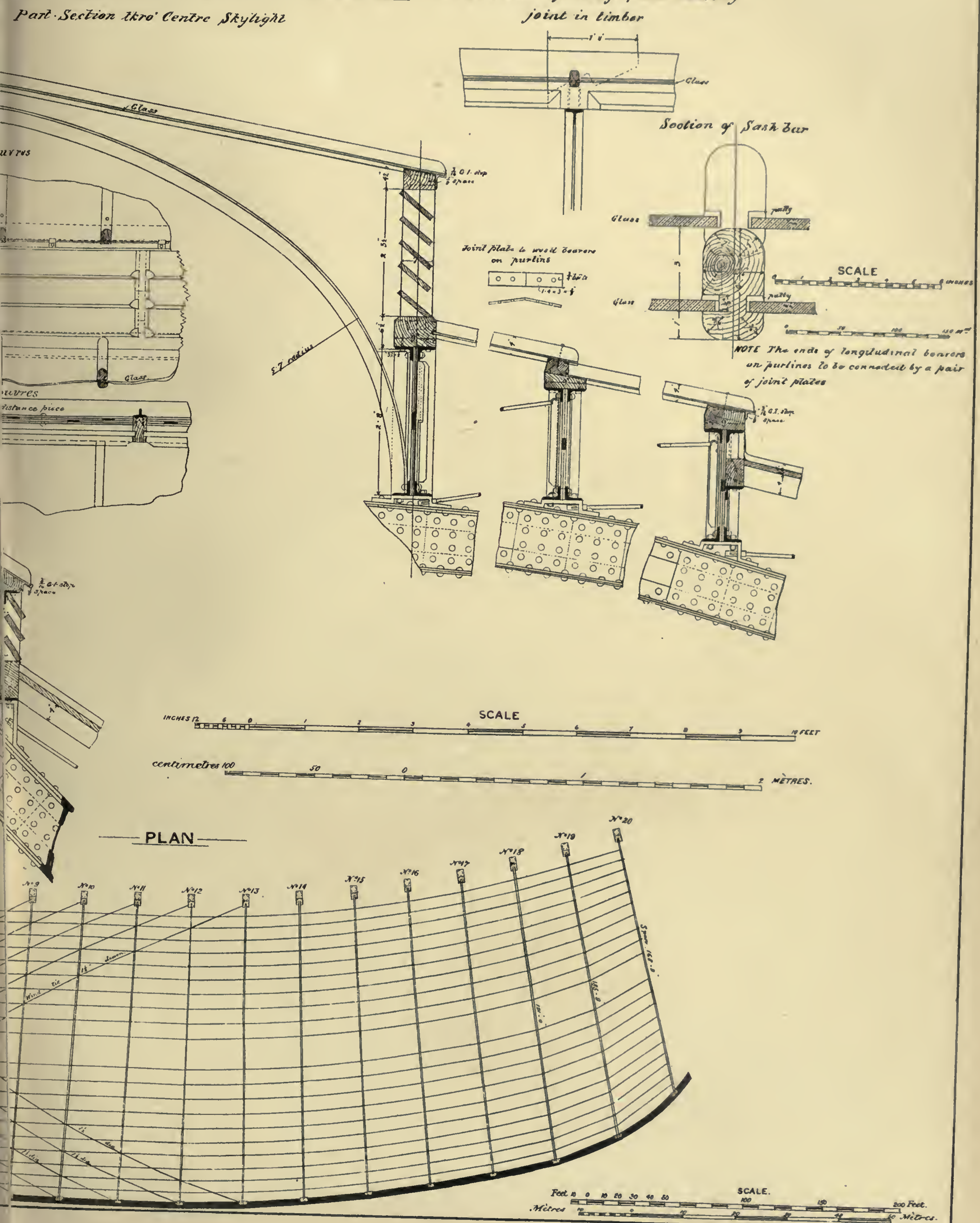
L. & N

LIME STREET STATION



W. R

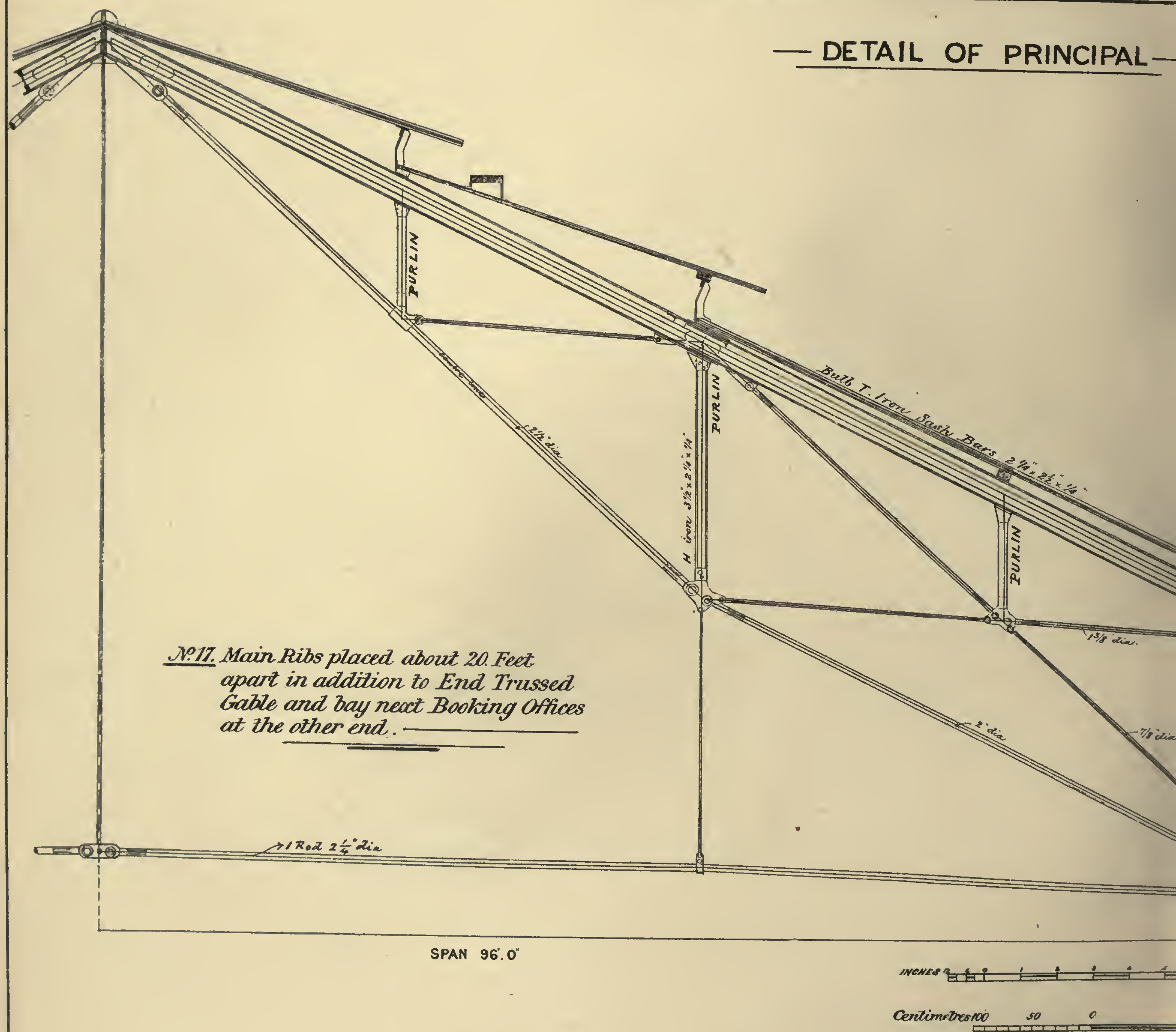
ROOF. LIVERPOOL.



METROPOLITAN DISTRICT RAILWAY.

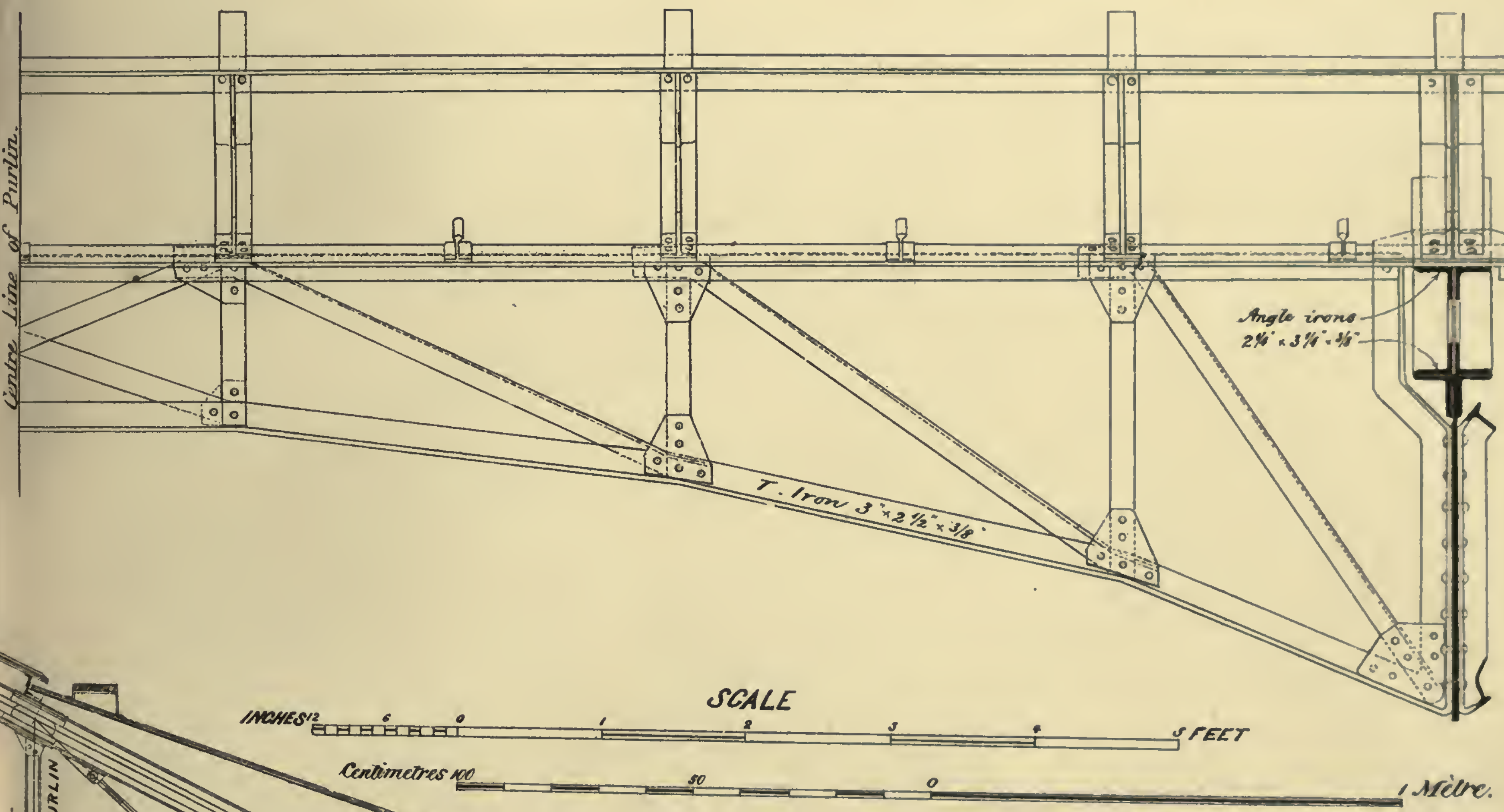
—EARLS COURT STAT

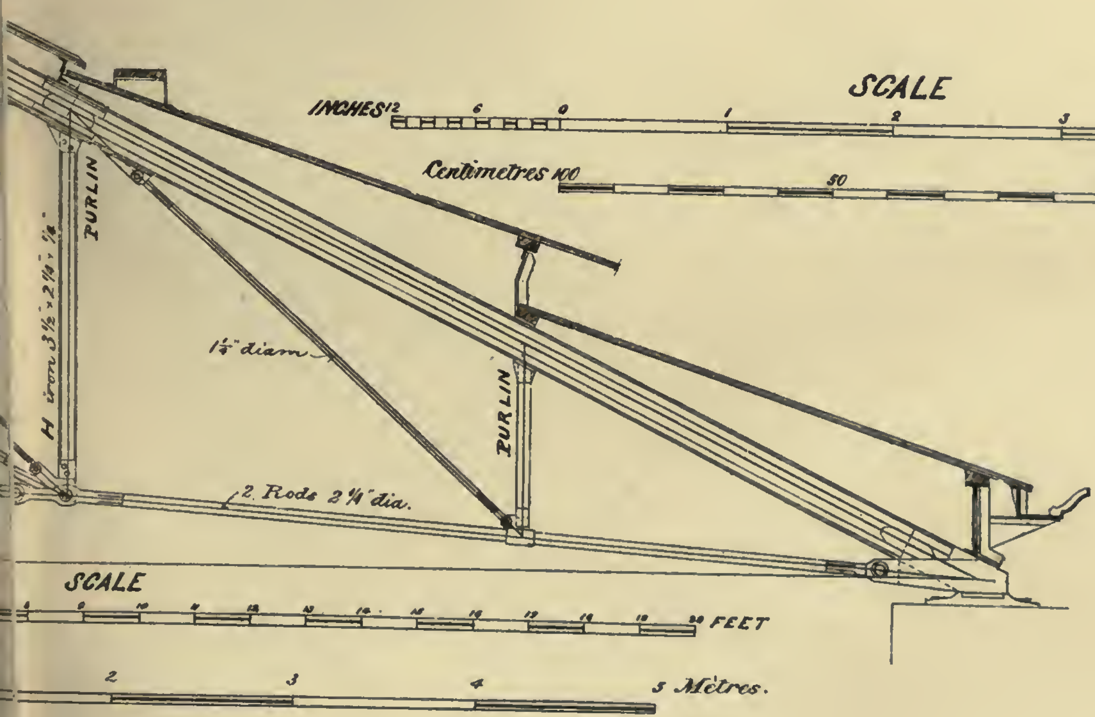
— DETAIL OF PRINCIPAL —



N

PURLIN.


Centre Line of Purlin.
Angle irons 2¼" × 3¼" × ⅜"
T. Iron 3" × 2½" × ⅜"
SCALE
INCHES 12 6 0 1 2 3 4 5 FEET
Centimetres 100 50 0 1 Mètre.


PURLIN
H iron 3½" × 2½" × ¼"
1½" diam.
PURLIN
2. Rods 2¼" dia.
SCALE
FEET
2 3 4 5 Mètres.

BY VARIOUS IRON ROOFS OVER LARGE BUILDINGS

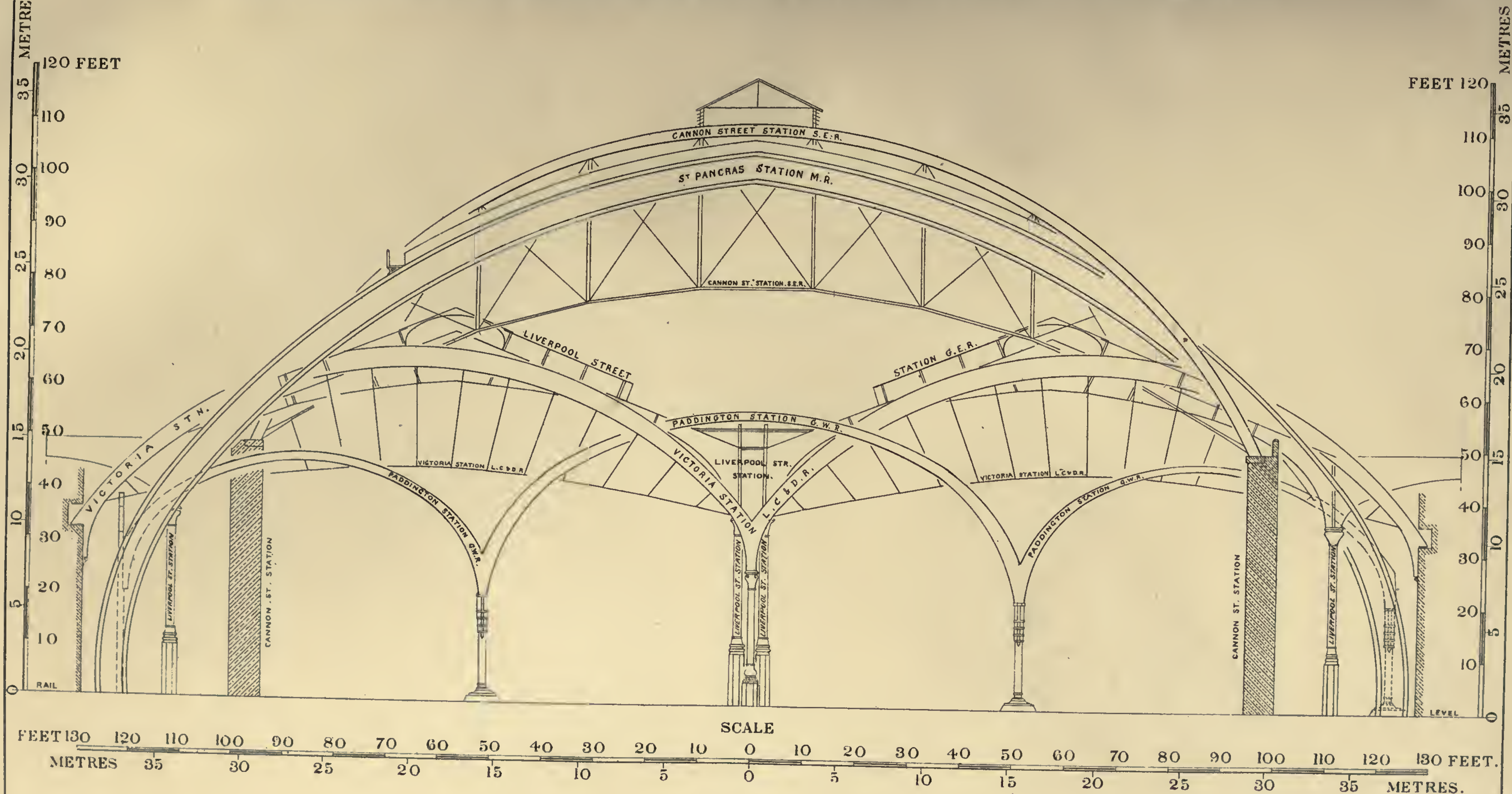
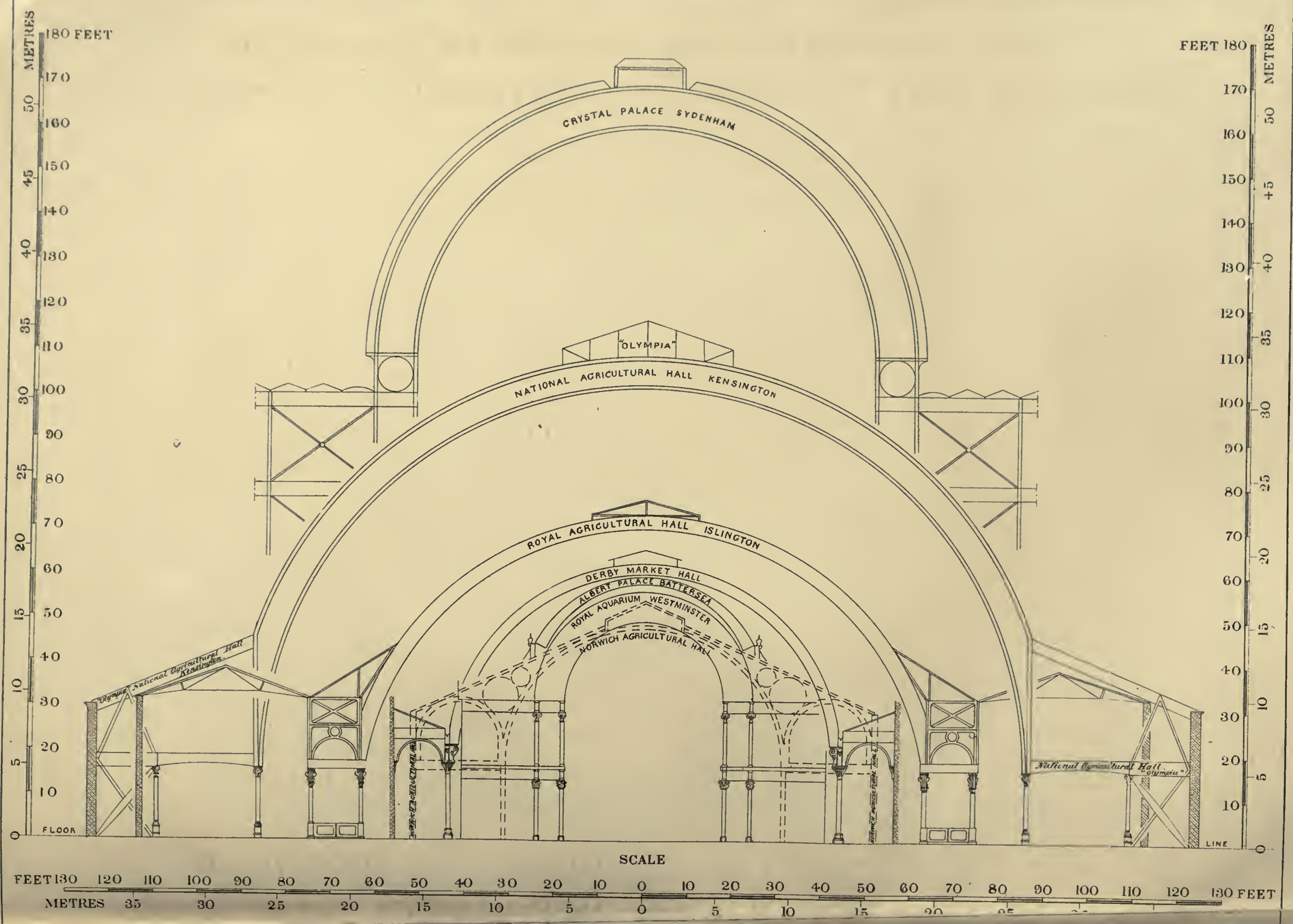


DIAGRAM No. 2 ILLUSTRATING THE VERTICAL AREA OCCUPIED
BY VARIOUS METROPOLITAN RAILWAY STATIONS

PLATE No. 70.

PHOTO-LITHO. SPRAGUE & Co LONDON.


CRYSTAL PALACE SYDENHAM
"OLYMPIA"
NATIONAL AGRICULTURAL HALL KENSINGTON
ROYAL AGRICULTURAL HALL ISLINGTON
DERBY MARKET HALL
ALBERT PALACE BATTERSEA
ROYAL AQUARIUM WESTMINSTER
NORWICH AGRICULTURAL HALL
"Olympia" National Agricultural Hall Kensington
National Agricultural Hall "Olympia"
FLOOR
LINE
FEET
METRES
SCALE

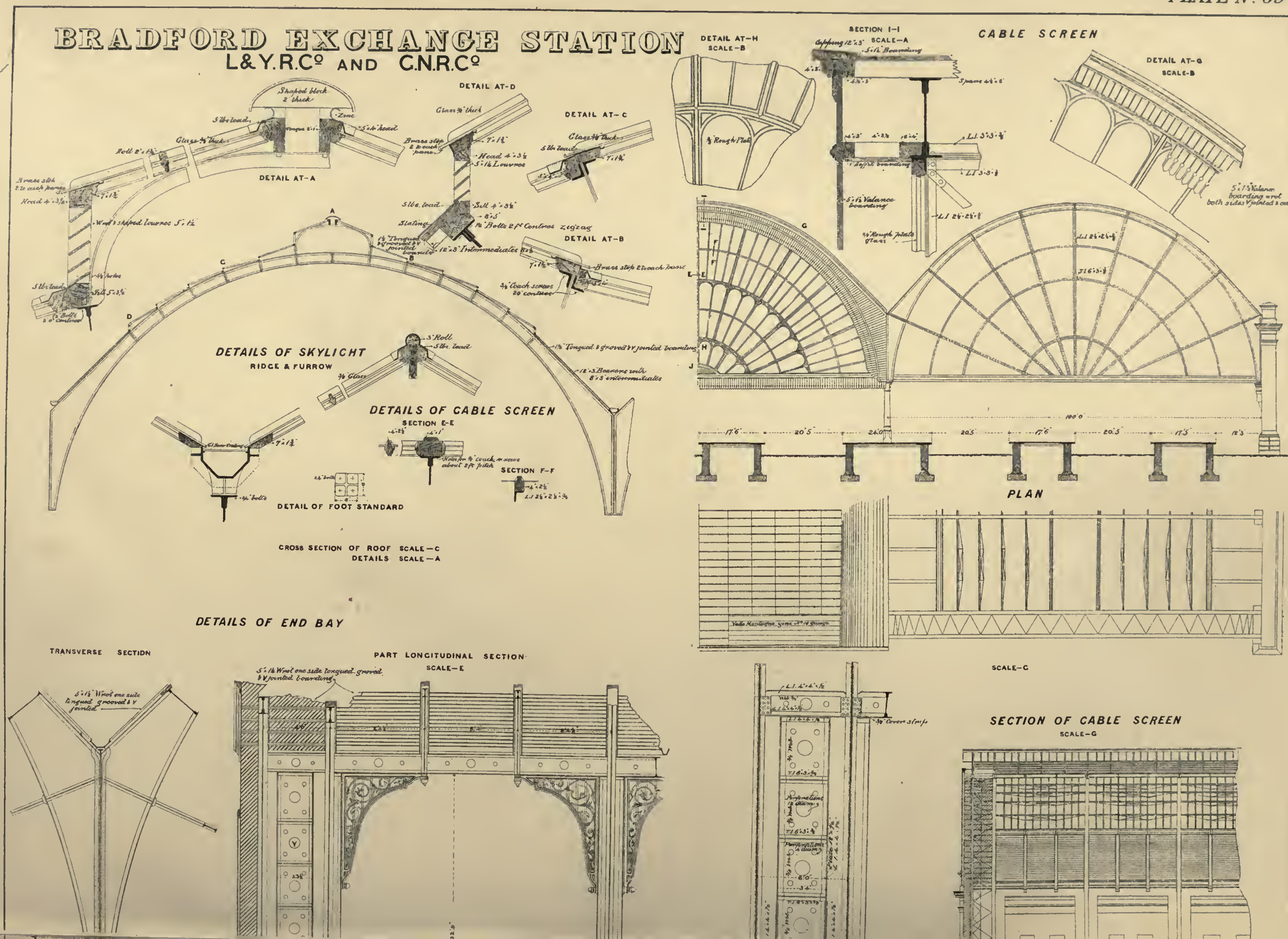

BRADFORD EXCHANGE STATION
L&Y.R.Cº AND G.N.R.Cº
DETAIL AT-A
DETAIL AT-D
DETAIL AT-C
DETAIL AT-B
DETAIL AT-H
SCALE-B
SECTION I-I
SCALE-A
CABLE SCREEN
DETAIL AT-G
SCALE-B
DETAILS OF SKYLICHT
RIDGE & FURROW
DETAILS OF CABLE SCREEN
SECTION E-E
SECTION F-F
DETAIL OF FOOT STANDARD
CROSS SECTION OF ROOF SCALE—C
DETAILS SCALE—A
PLAN
DETAILS OF END BAY
TRANSVERSE SECTION
PART LONGITUDINAL SECTION
SCALE—E
SCALE—C
SECTION OF CABLE SCREEN
SCALE—G

PLATE No. 69

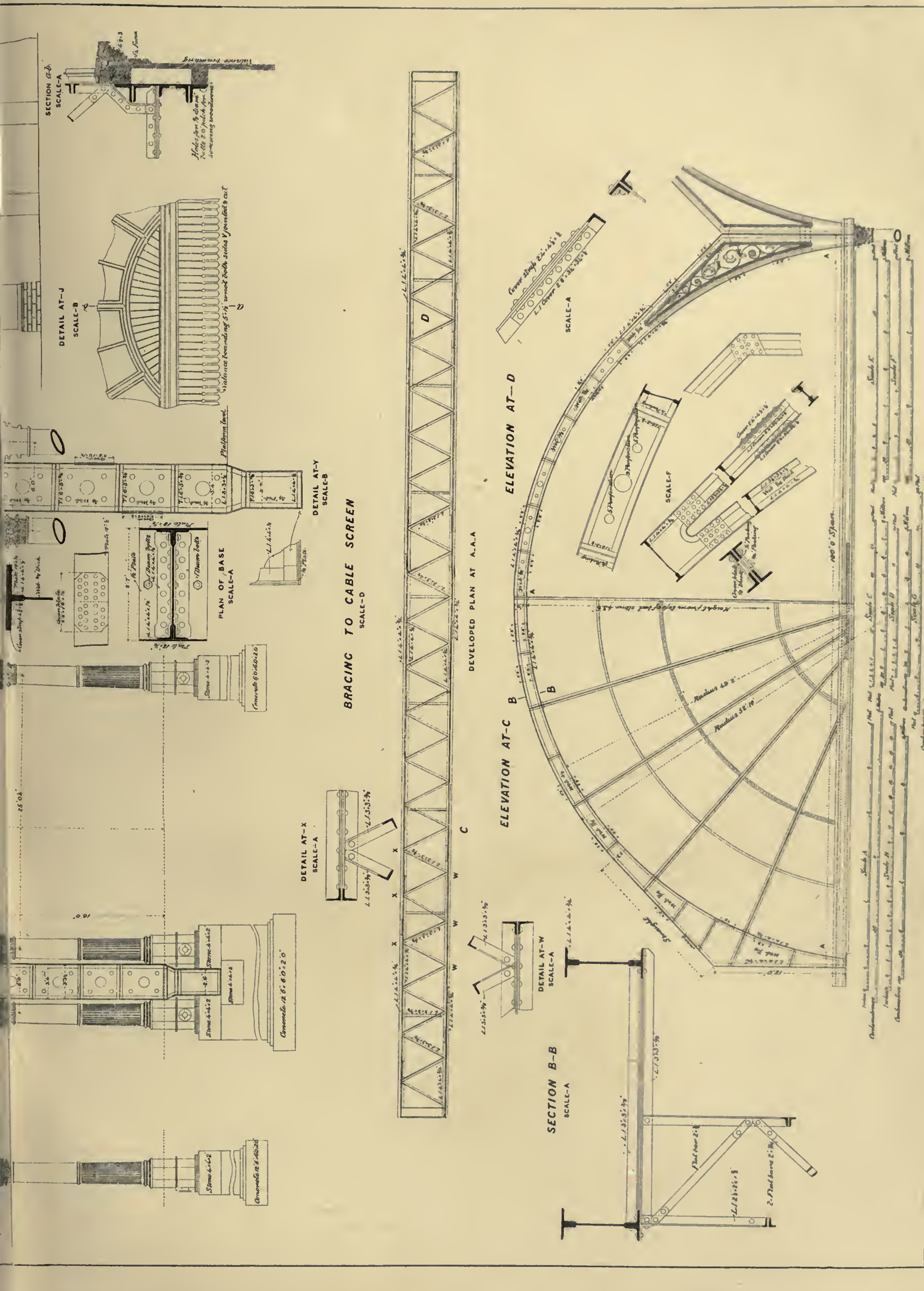
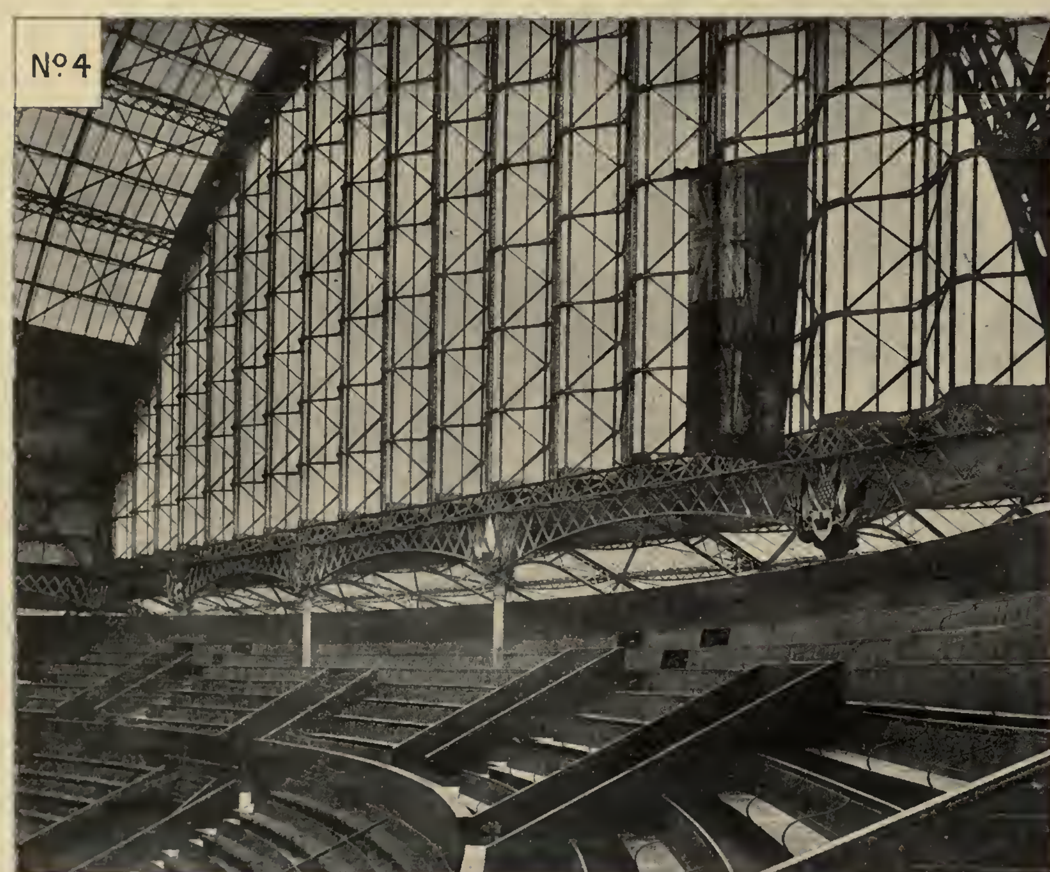


PHOTO-LITHO, SPRAGUE & Co LONDON

THE NATIONAL AG

Nº 1

Nº 2



Nº 4

Nº 5

OLYMPIA – K

RICULTURAL HALL,

PLATE No. 68.

No. 3

No. 6

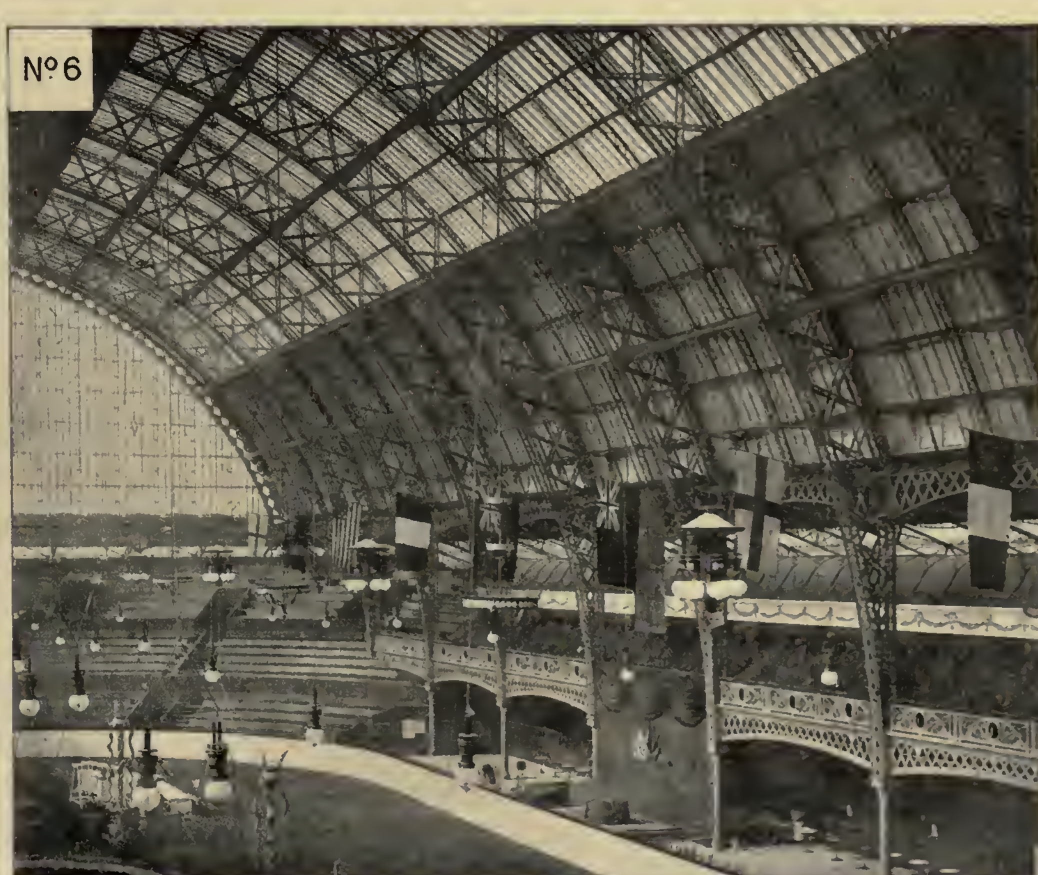
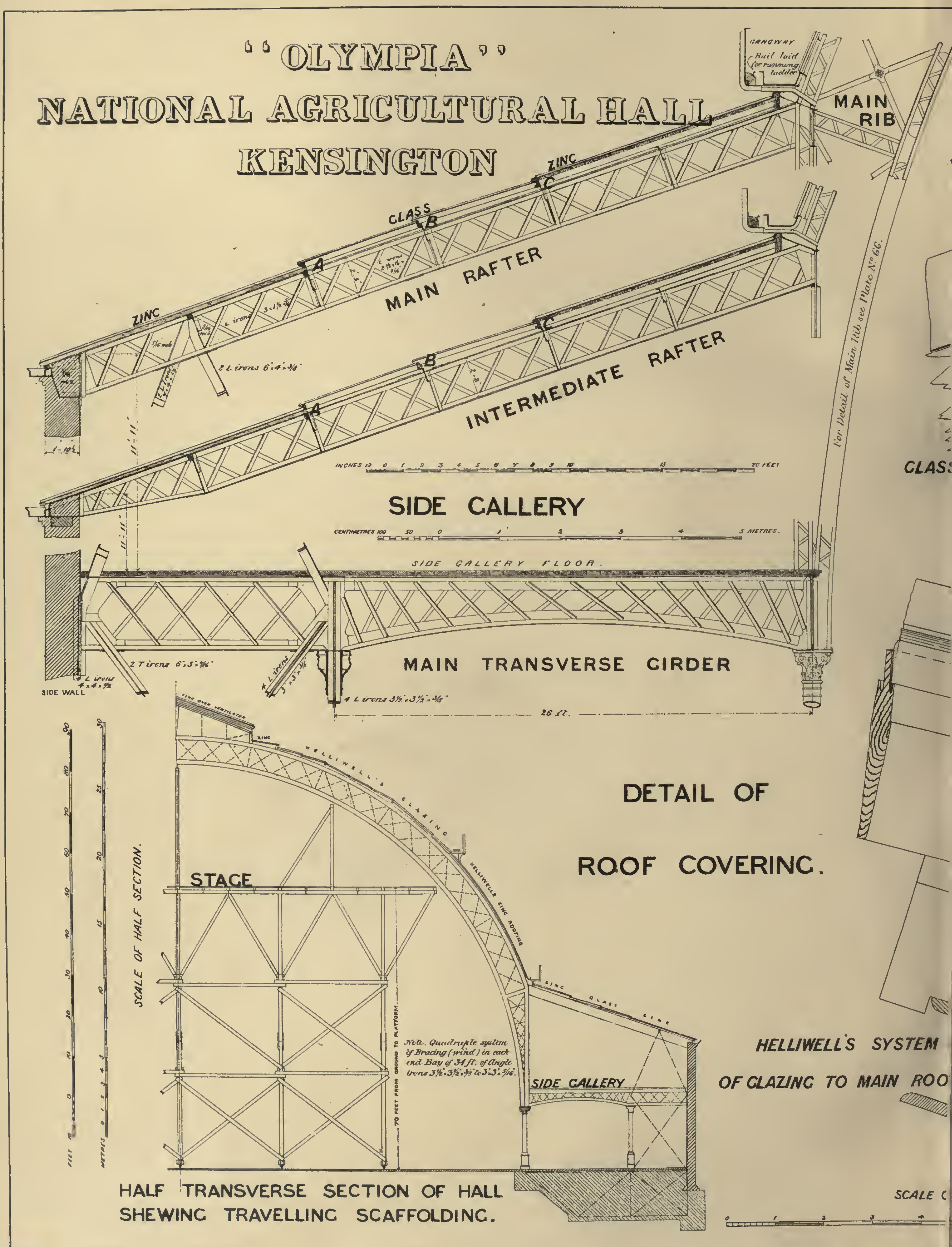
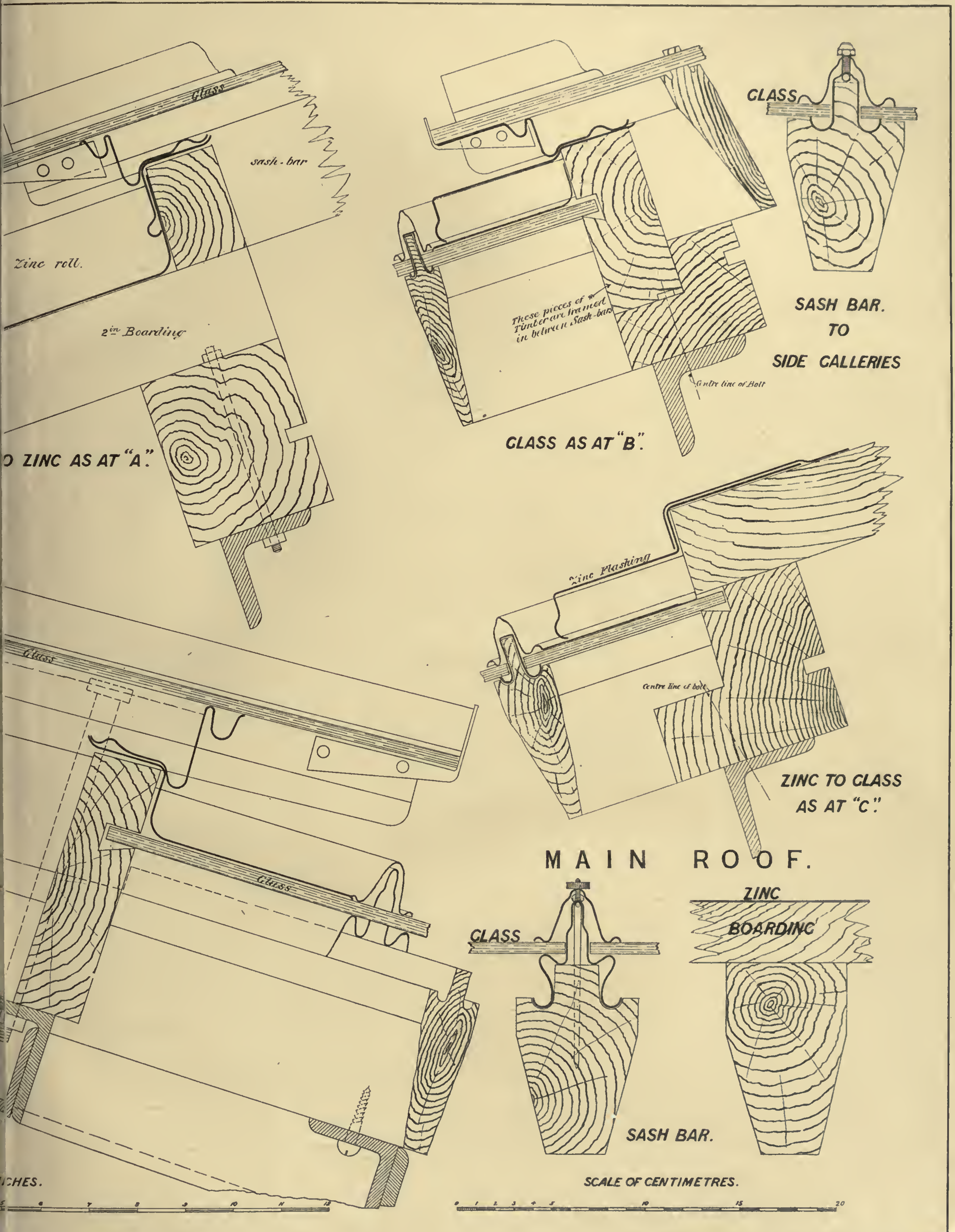


PHOTO. SPRAGUE & Co 22, MARTINS LANE CANNON St LONDON E.C

ENSINGTON.


"OLYMPIA"
NATIONAL AGRICULTURAL HALL
KENSINGTON
GANGWAY
Rail laid for running ladder
MAIN RIB
ZINC
GLASS
MAIN RAFTER
2 L irons 6"x4"x3/8"
INTERMEDIATE RAFTER
For Detail of Main Rib see Plate No 66.
SIDE GALLERY
SIDE GALLERY FLOOR.
MAIN TRANSVERSE GIRDER
SIDE WALL
26 ft.
HELLIWELL'S GLAZING
HELLIWELL'S ZINC ROOFING
STAGE
SCALE OF HALF SECTION.
Note. Quadruple system of Bracing (wind) in each end Bay of 34 ft. of Angle irons 3½"x3½"x3/8" to 3"x3"x5/16".
70 FEET FROM GROUND TO PLATFORM.
SIDE GALLERY
DETAIL OF
ROOF COVERING.
HELLIWELL'S SYSTEM
OF GLAZING TO MAIN ROO
HALF TRANSVERSE SECTION OF HALL
SHEWING TRAVELLING SCAFFOLDING.
SCALE


Glass
sash-bar
Zinc roll.
2in Boarding
O ZINC AS AT "A".
CLASS
SASH BAR.
TO
SIDE CALLERIES
These pieces of Timber are framed in between Sash-bars
Centre line of Bolt
CLASS AS AT "B".
Zinc Flashing
Centre line of bolt
ZINC TO CLASS
AS AT "C".
Glass
Glass
MAIN ROOF.
ZINC
BOARDINC
CLASS
SASH BAR.
ICHES.
SCALE OF CENTIMETRES.
0 1 2 3 4 5 10 15 20

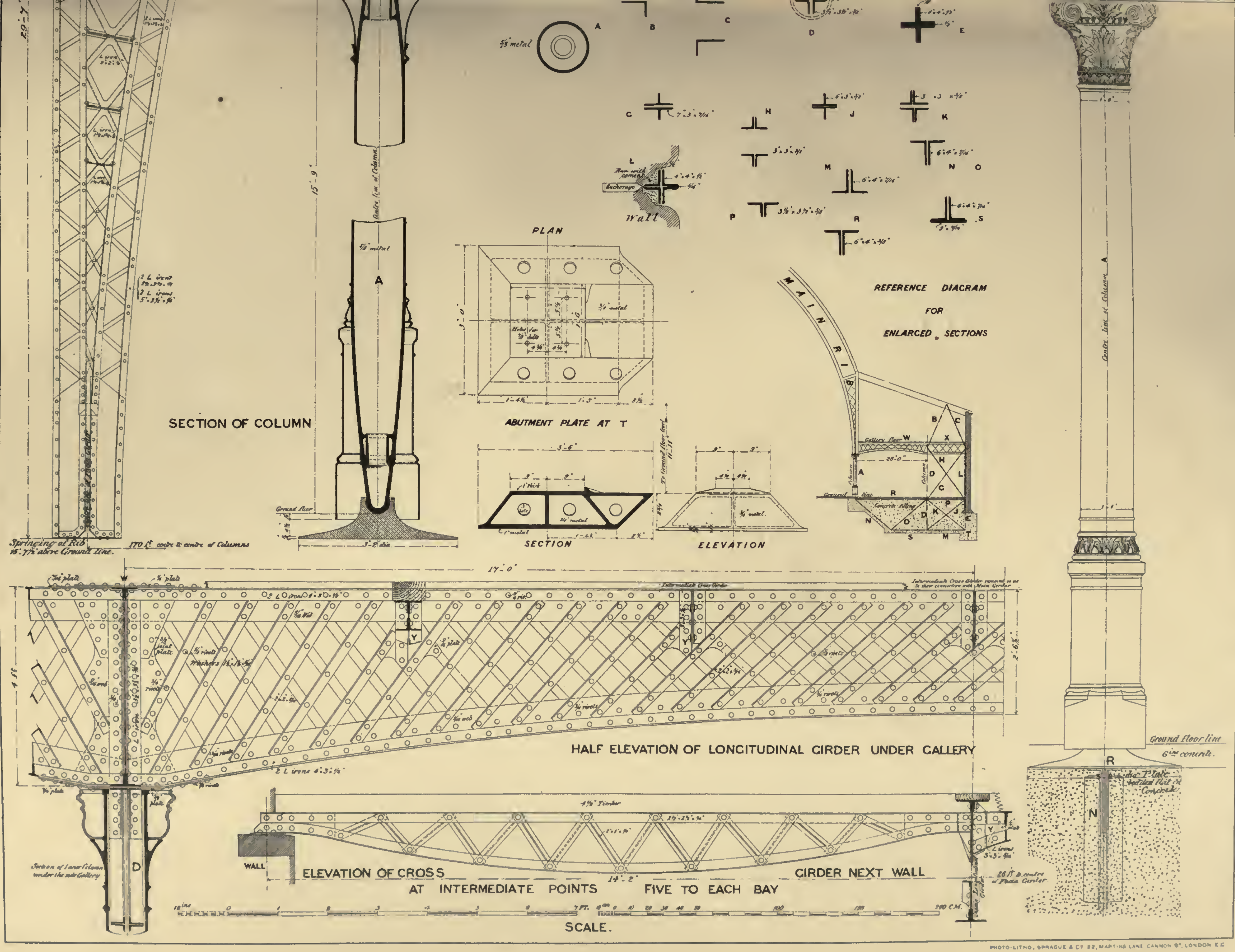
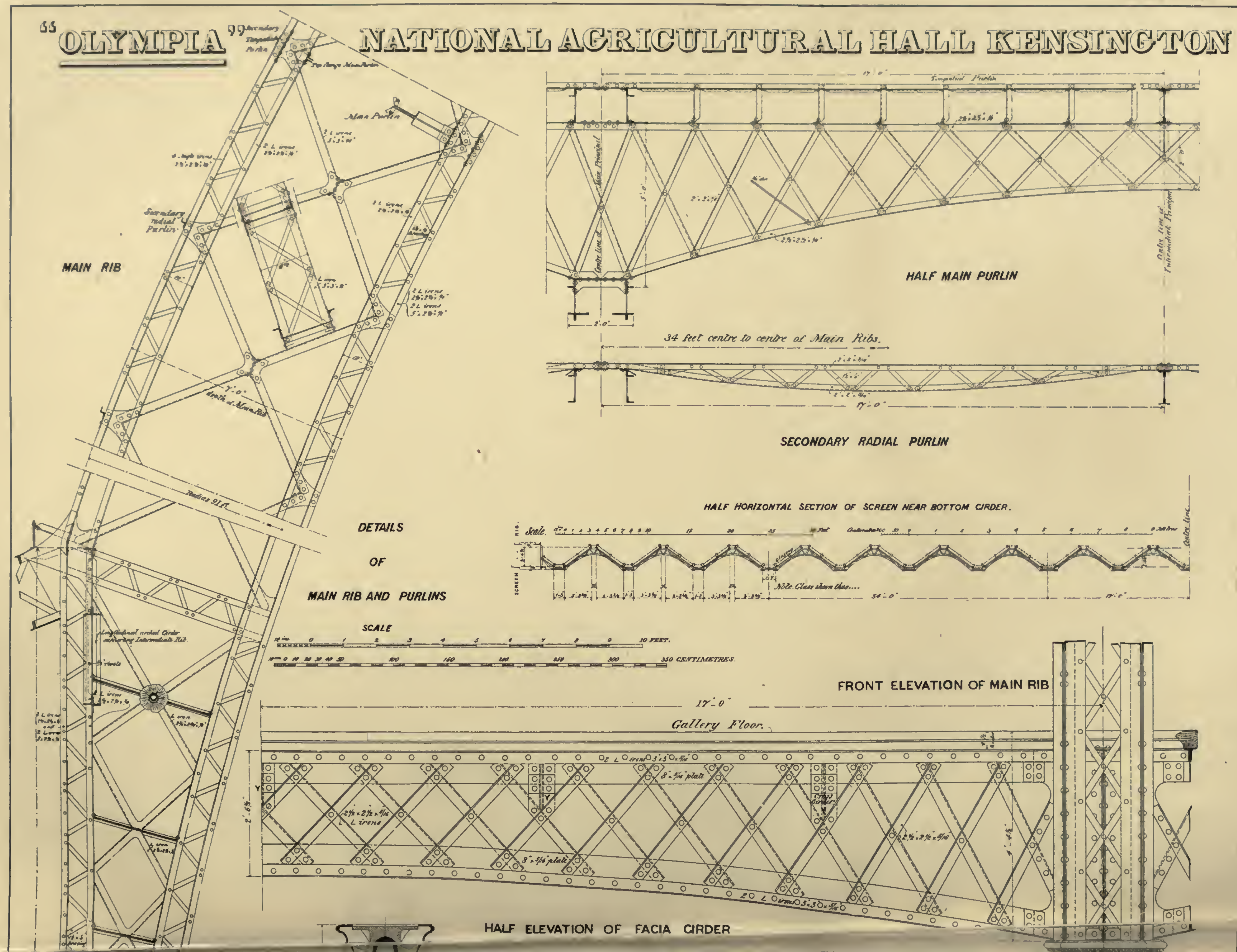


PLATE N° 66.

PHOTO-LITHO, SPRAGUE & Cº 22, MARTINS LANE CANNON Sᵀ LONDON E.C.

"OLYMPIA" NATIONAL AGRICULTURAL HALL KENSINGTON



NATIONAL AGRICULTURAL HALL KENSINGTON

TRANSVERSE SECTION

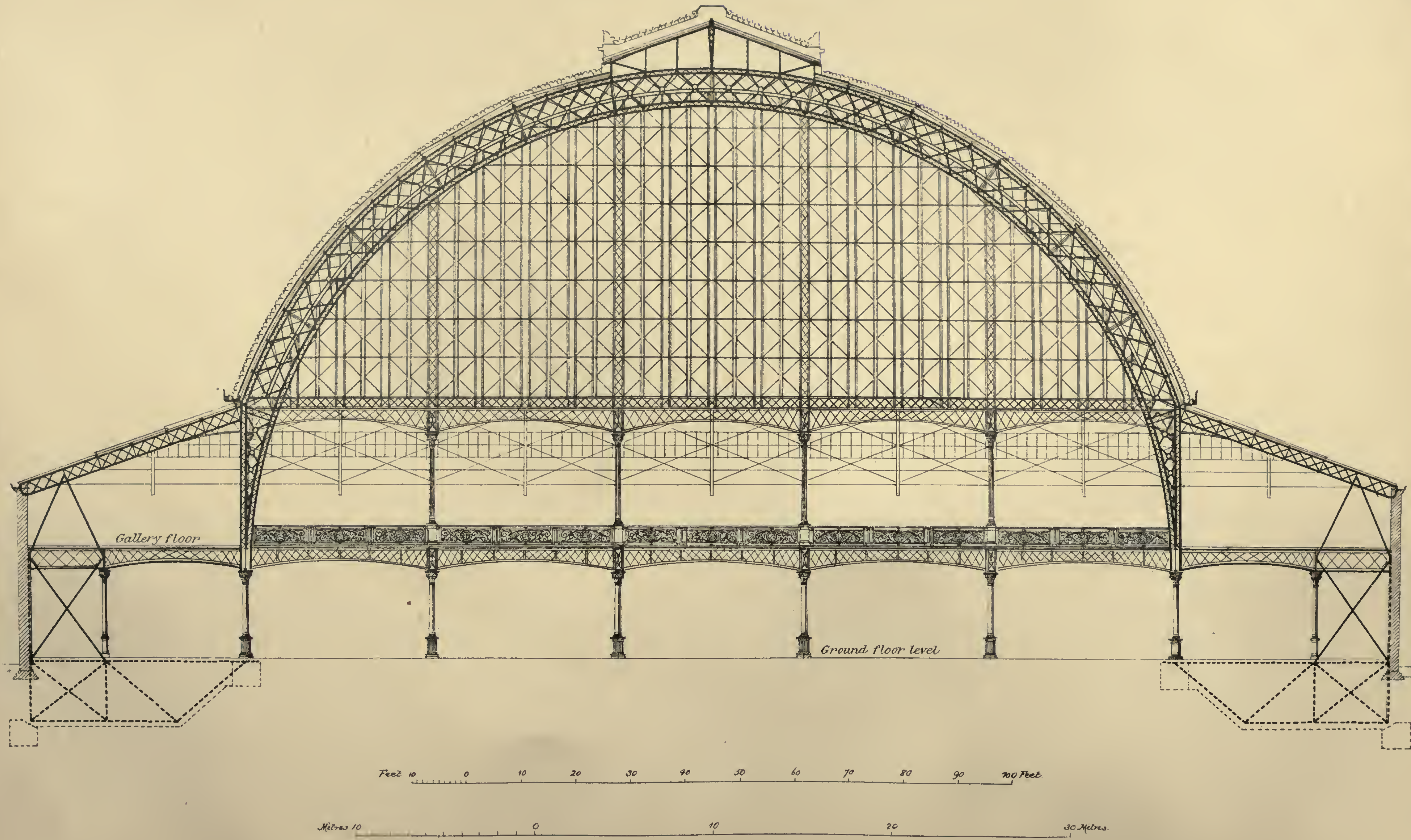
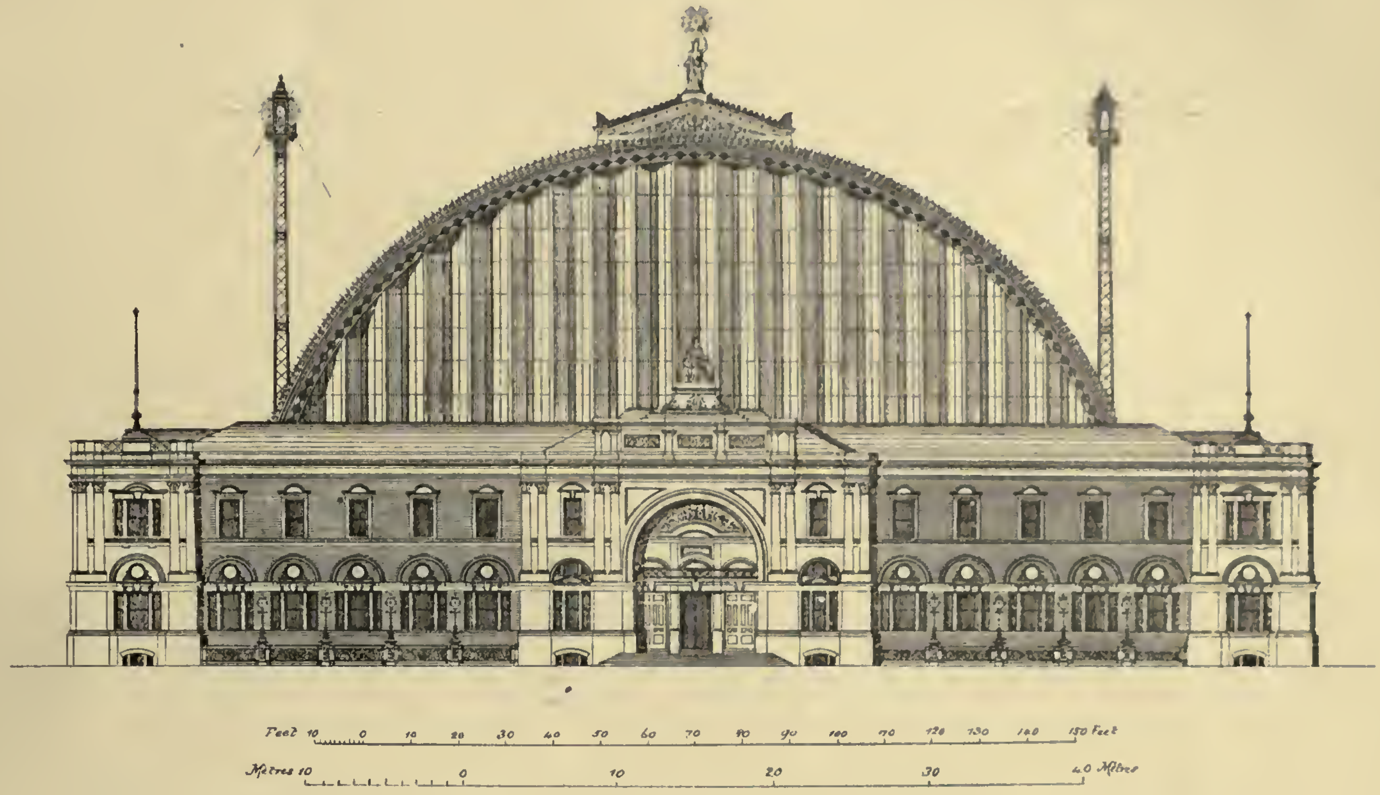


PHOTO-LITHO SPRAGUE & Co LONDON

NATIONAL AGRICULTURAL HALL

EAST ELEVATION



PLAN

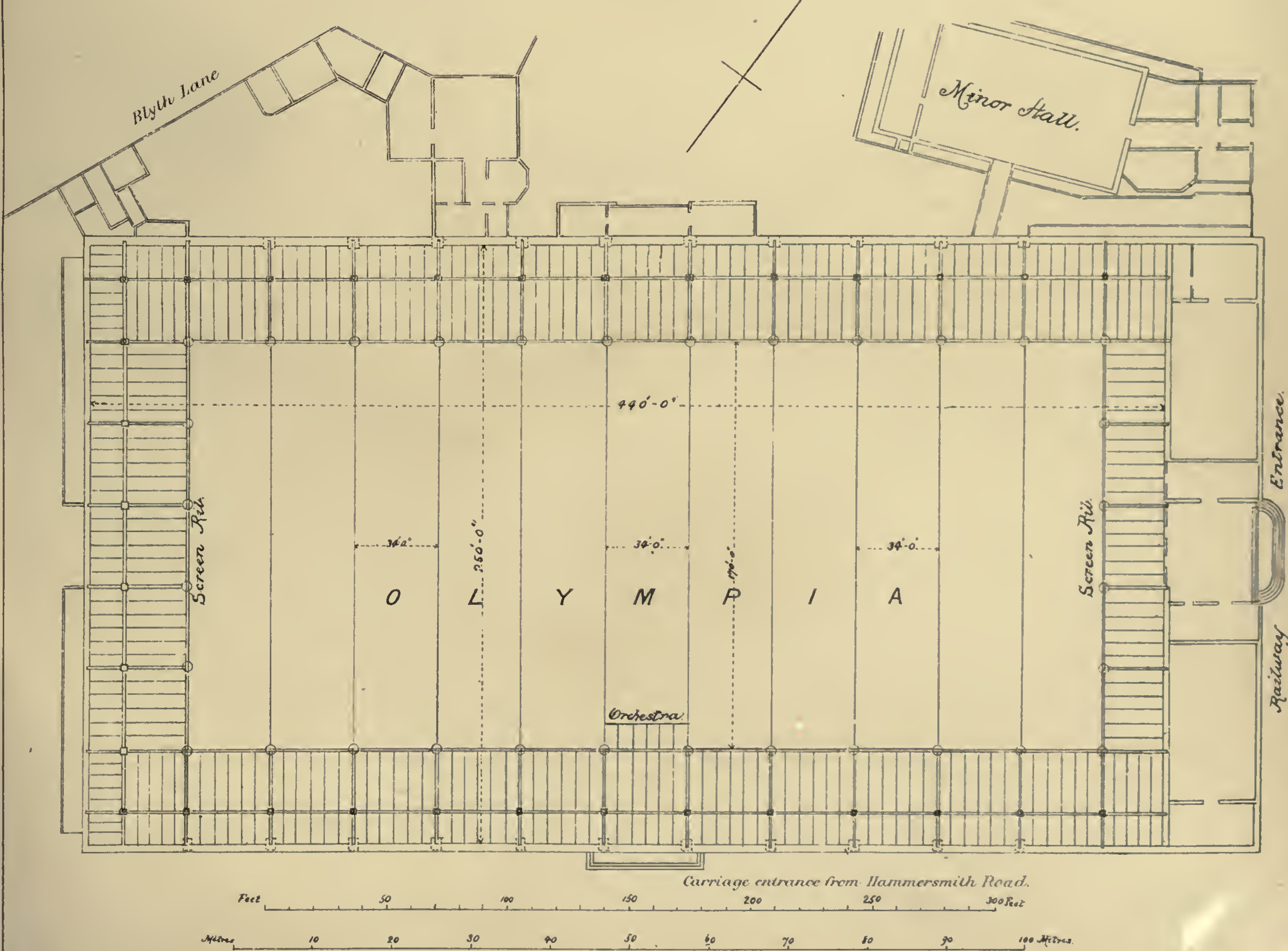


PHOTO-LITHO SPRAGUE & Cº LONDON

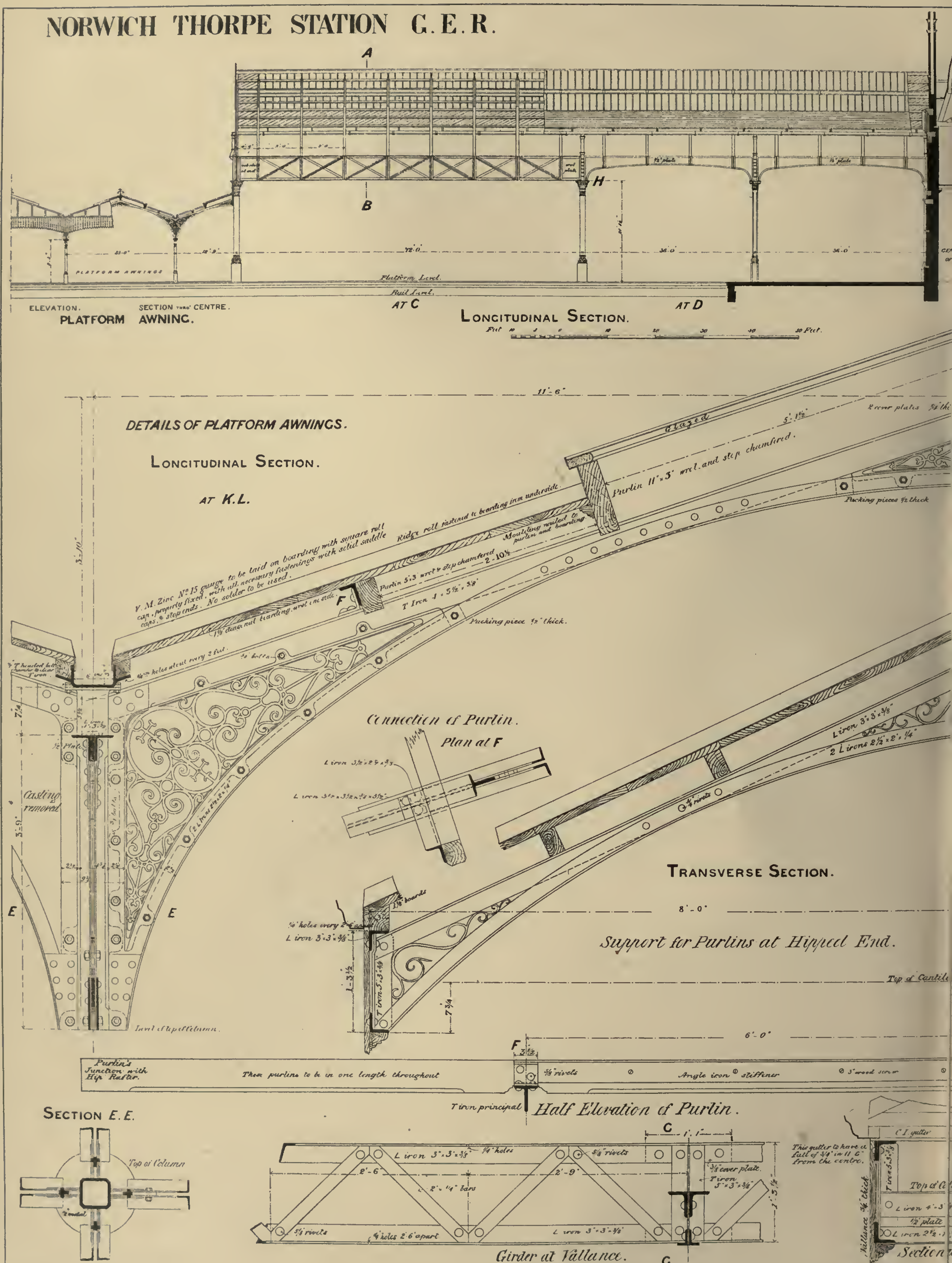
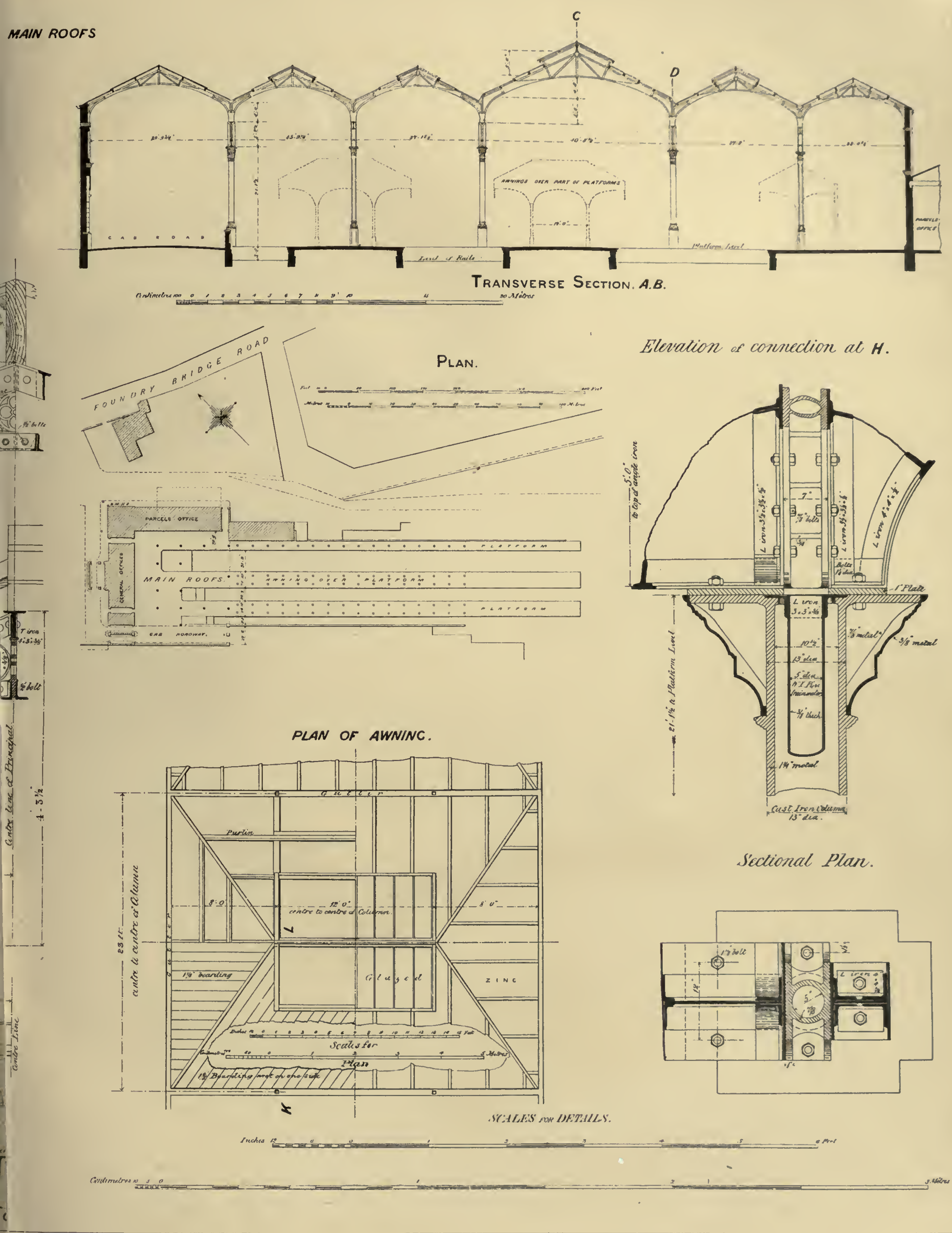
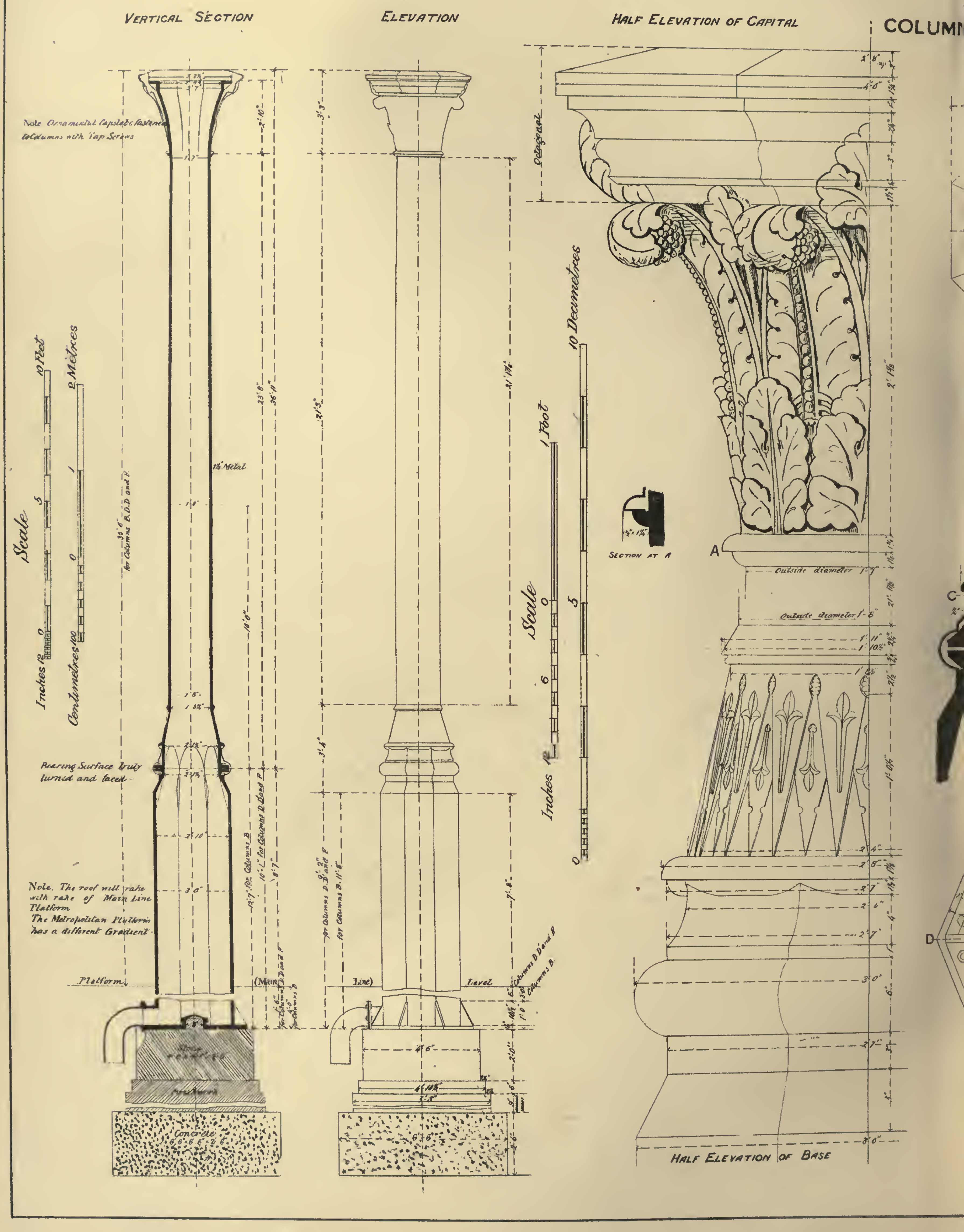


PHOTO LITHO SPRAGUE & Co LONDON

PLATE No 64.


MAIN ROOFS
C
D
AWNINGS OVER PART OF PLATFORMS
CAB ROAD
PARCELS OFFICE
Level of Rails
Platform level
TRANSVERSE SECTION. A.B.
Centimetres 100
20 Mètres
PLAN.
FOUNDRY BRIDGE ROAD
PARCELS OFFICE
GENERAL OFFICES
MAIN ROOFS
AWNING OVER PLATFORM
PLATFORM
CAB ROADWAY
Elevation of connection at H.
5'0" to top of angle iron
L iron 3½×3½×½
L iron 4×4×½
1" Plate
L iron 3×3×⅜
⅞ metal
⅝ metal
10½"
13" dia
5" dia W.I. Pipe
1¼" metal
21'-1½ to Platform Level
Cast Iron Column 13" dia.
Sectional Plan.
1⅛ bolt
14"
5"
PLAN OF AWNING.
Gutter
Purlin
8'0"
12'0" centre to centre of Columns
8'0"
23 ft. centre to centre of Column
1⅛" boarding
Glazed
ZINC
Scales for Plan
Metres
1⅛ Boarding over on one side
Centre line of Principal
4'-3½
Centre Line
T iron
¾ bolt
SCALES FOR DETAILS.
Inches 12
6 Feet
Centimetres 10
3 Mètres

LIVERPOOL STREET STATION. G.



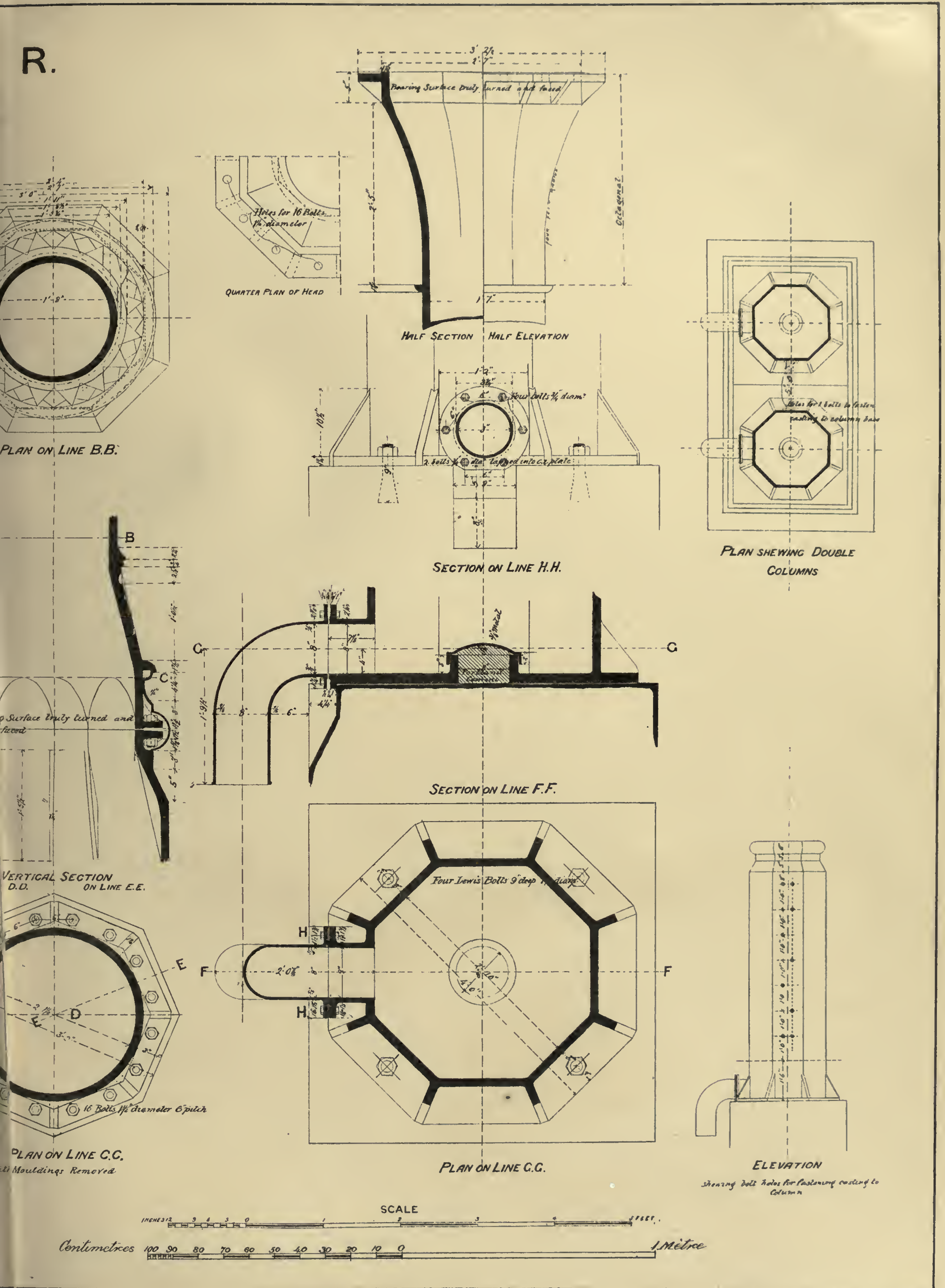
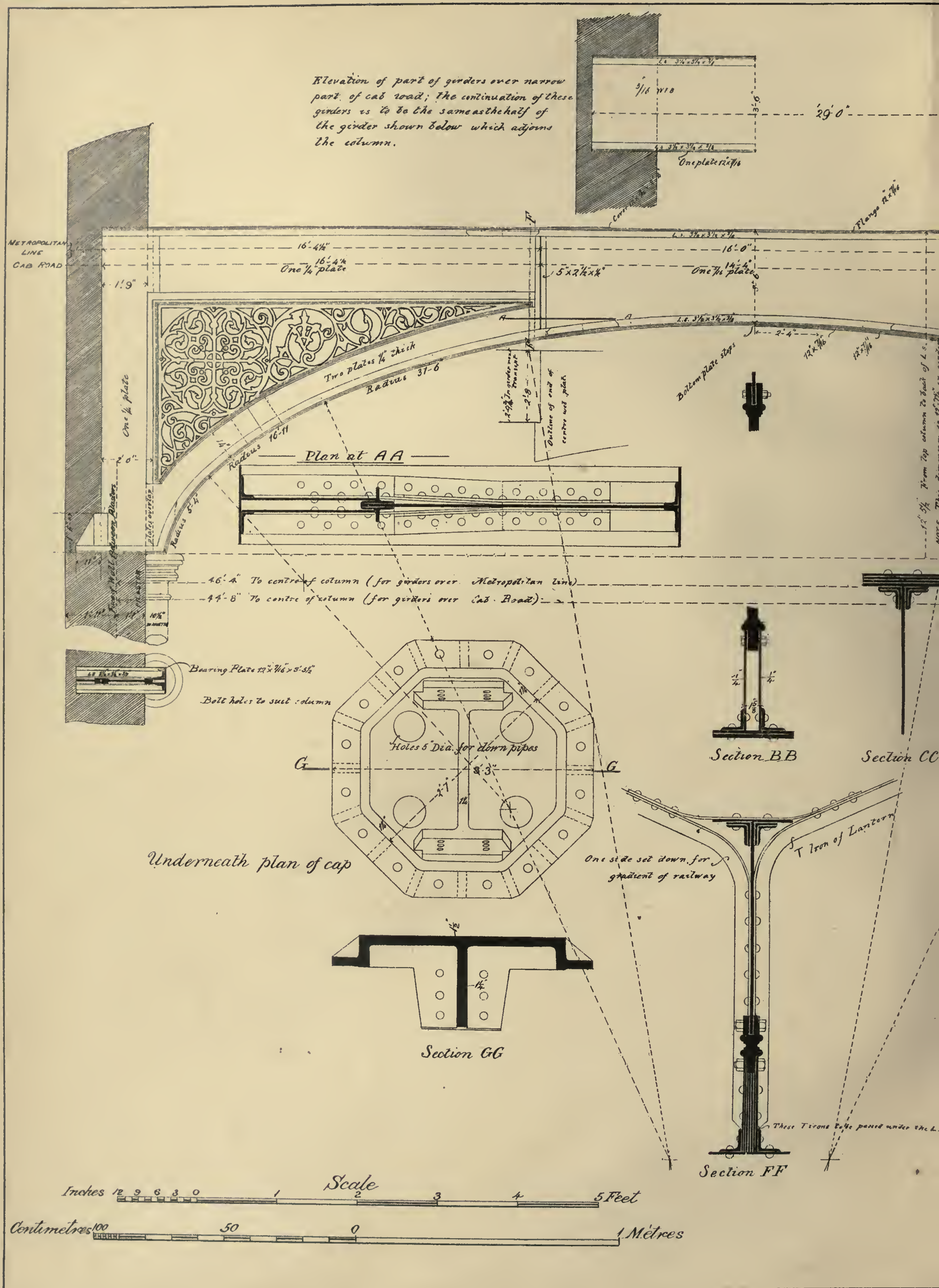


PHOTO-LITHO, SPRAGUE & Co. LONDON.


Elevation of part of girders over narrow part of cab road; the continuation of these girders is to be the same as the half of the girder shown below which adjoins the column.
29'0"
Metropolitan Line
Cab Road
16'-4½"
One ¼" plate
16'-0"
14'-4"
One 7/16" plate
1'.9"
5×2½×½
Two plates ¼" thick
Radius 37-6
Radius 16-11
Radius 5-4
Bottom plate steps
Plan at AA
46'-4" To centre of column (for girders over Metropolitan Line)
44'-8" To centre of column (for girders over Cab Road)
Bearing Plate
Bolt holes to suit column
Holes 5" Dia. for down pipes
G
G
Underneath plan of cap
Section BB
Section CC
One side set down for gradient of railway
T Iron of Lantern
Section GG
These T irons to be passed under the L.
Section FF
Scale
Inches 12 9 6 3 0 1 2 3 4 5 Feet
Centimetres 100 50 0 1 Mètres

LIVERPOOL STREET STATION
G. E. R.

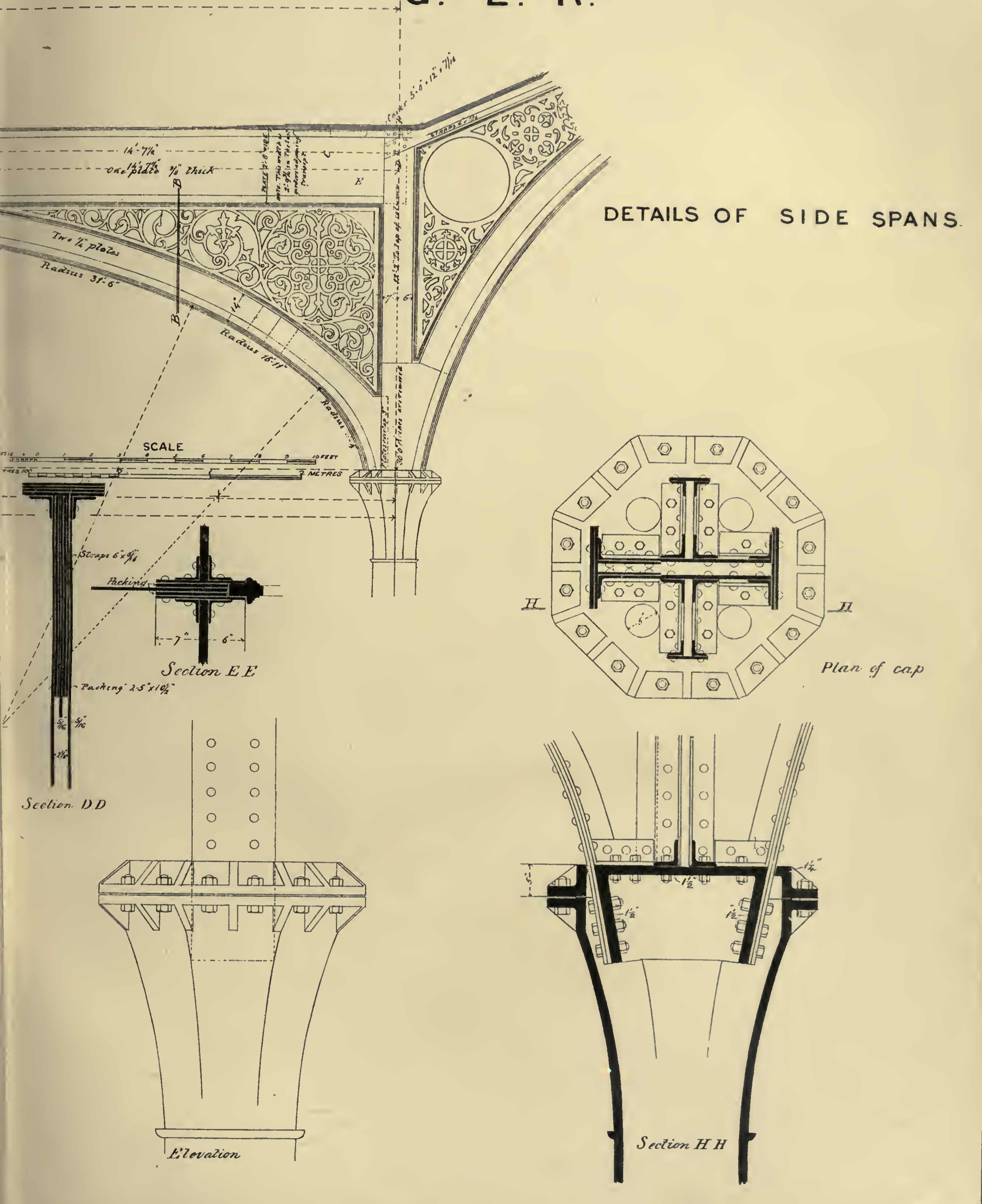
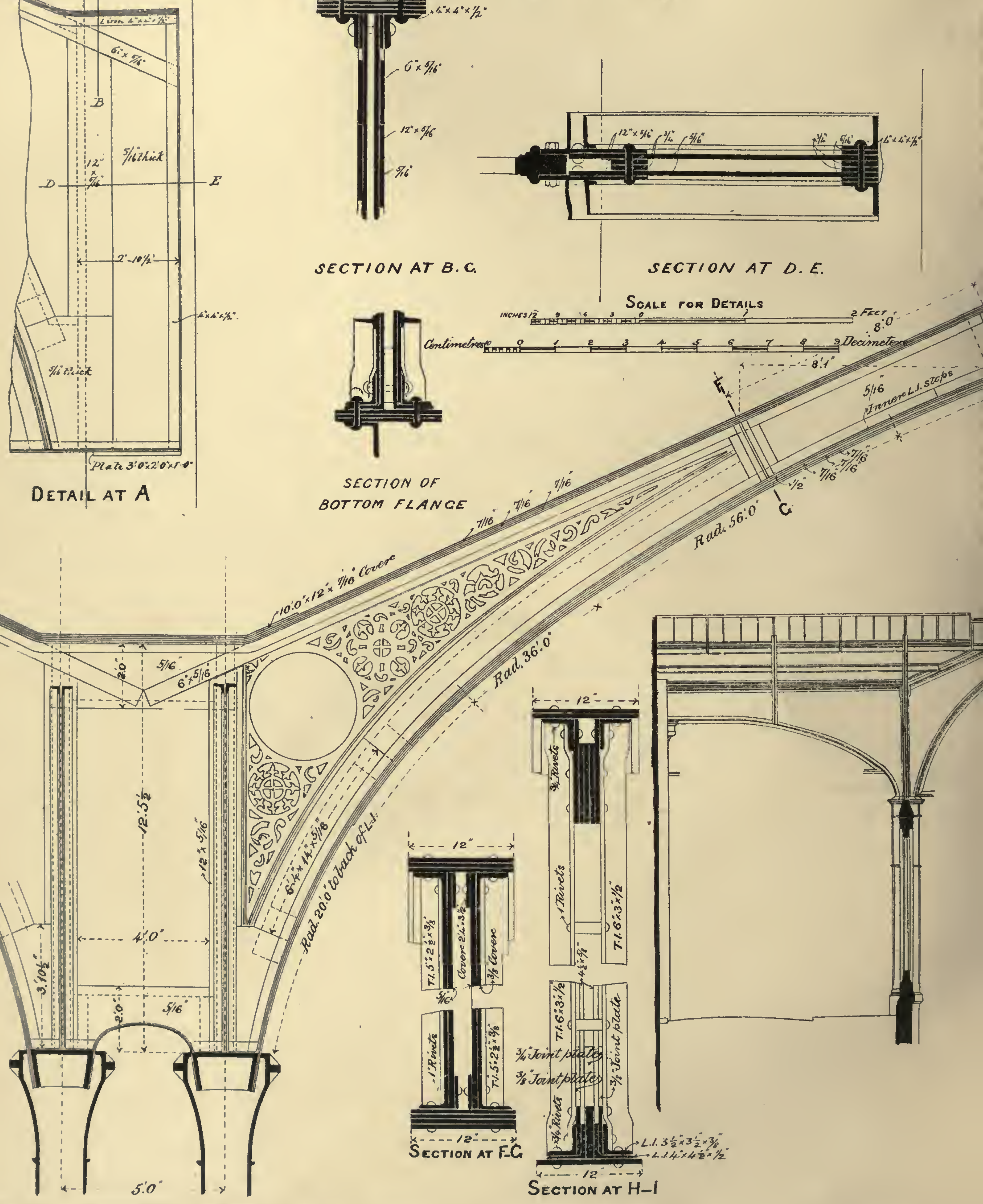
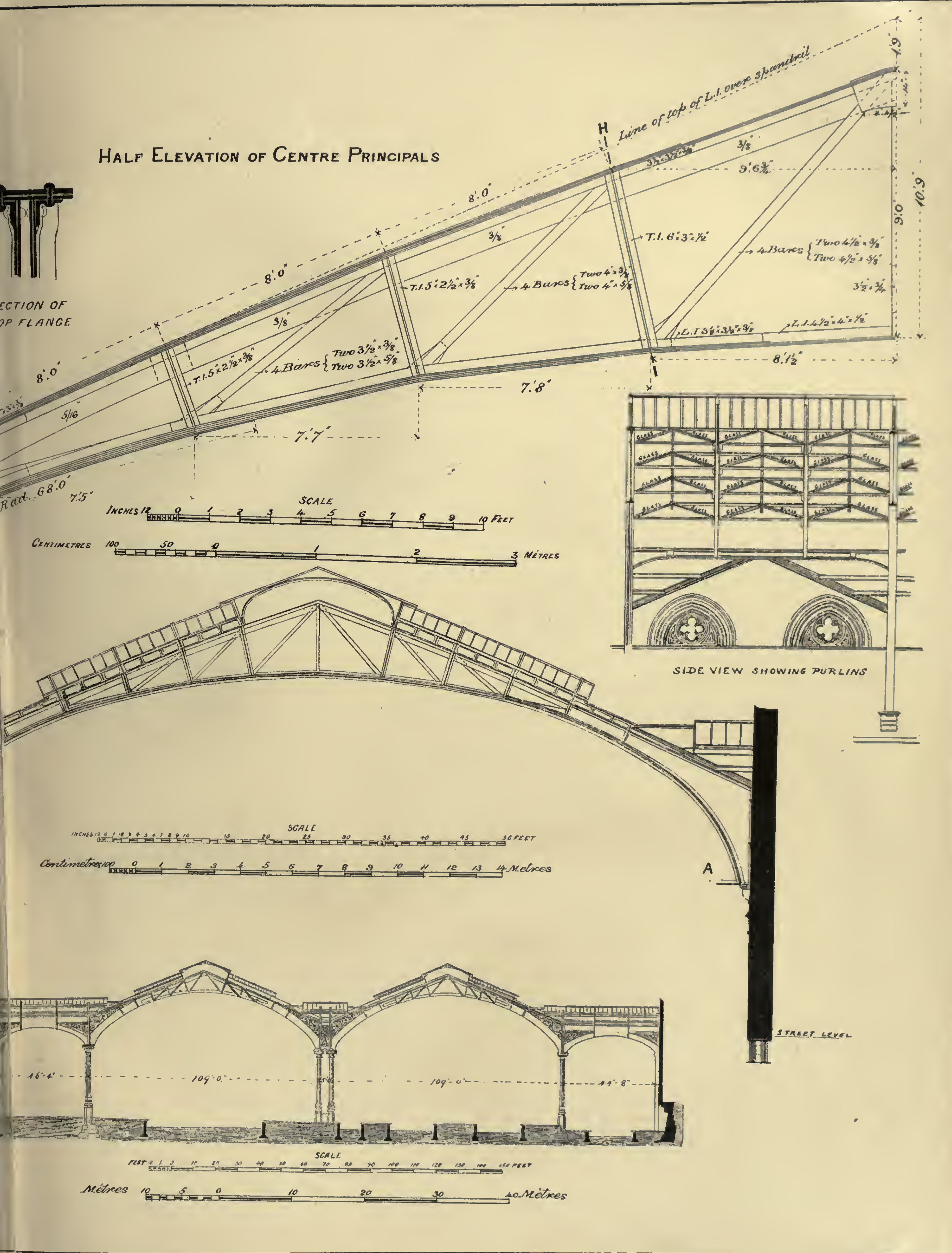


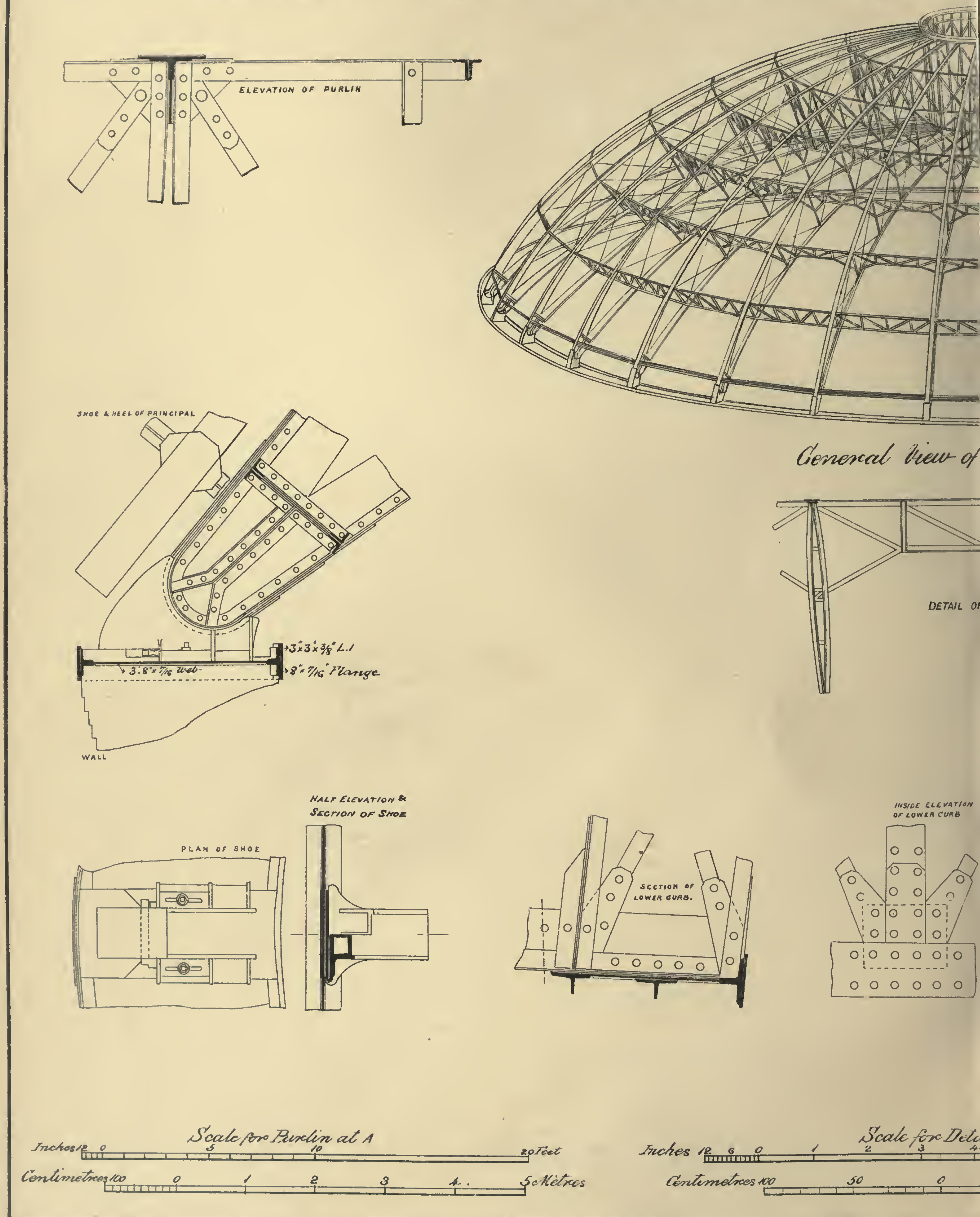
PHOTO-LITHO, SPRAGUE & Co. LONDON.

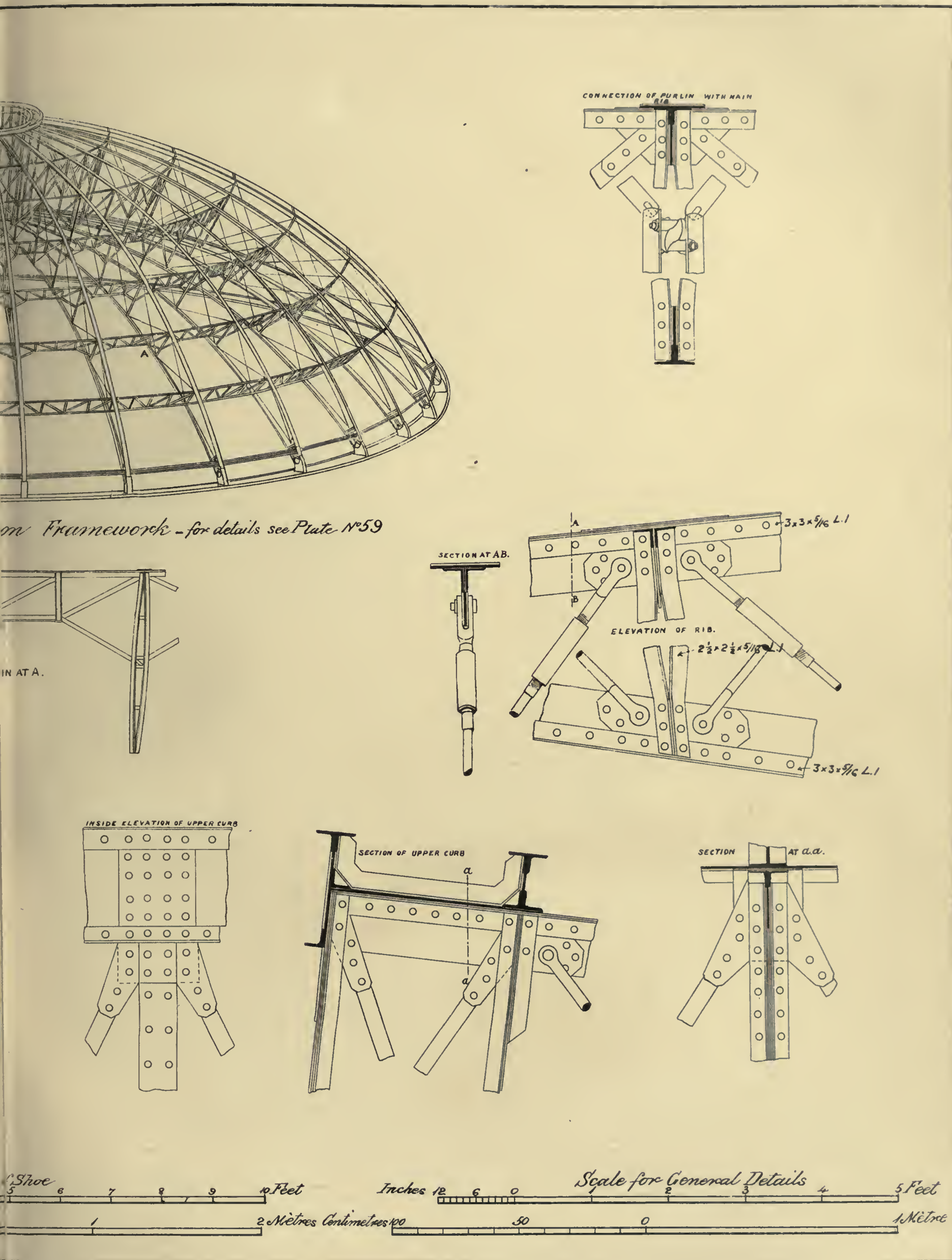
LIVERPOOL STREET STATION
G. E. R.



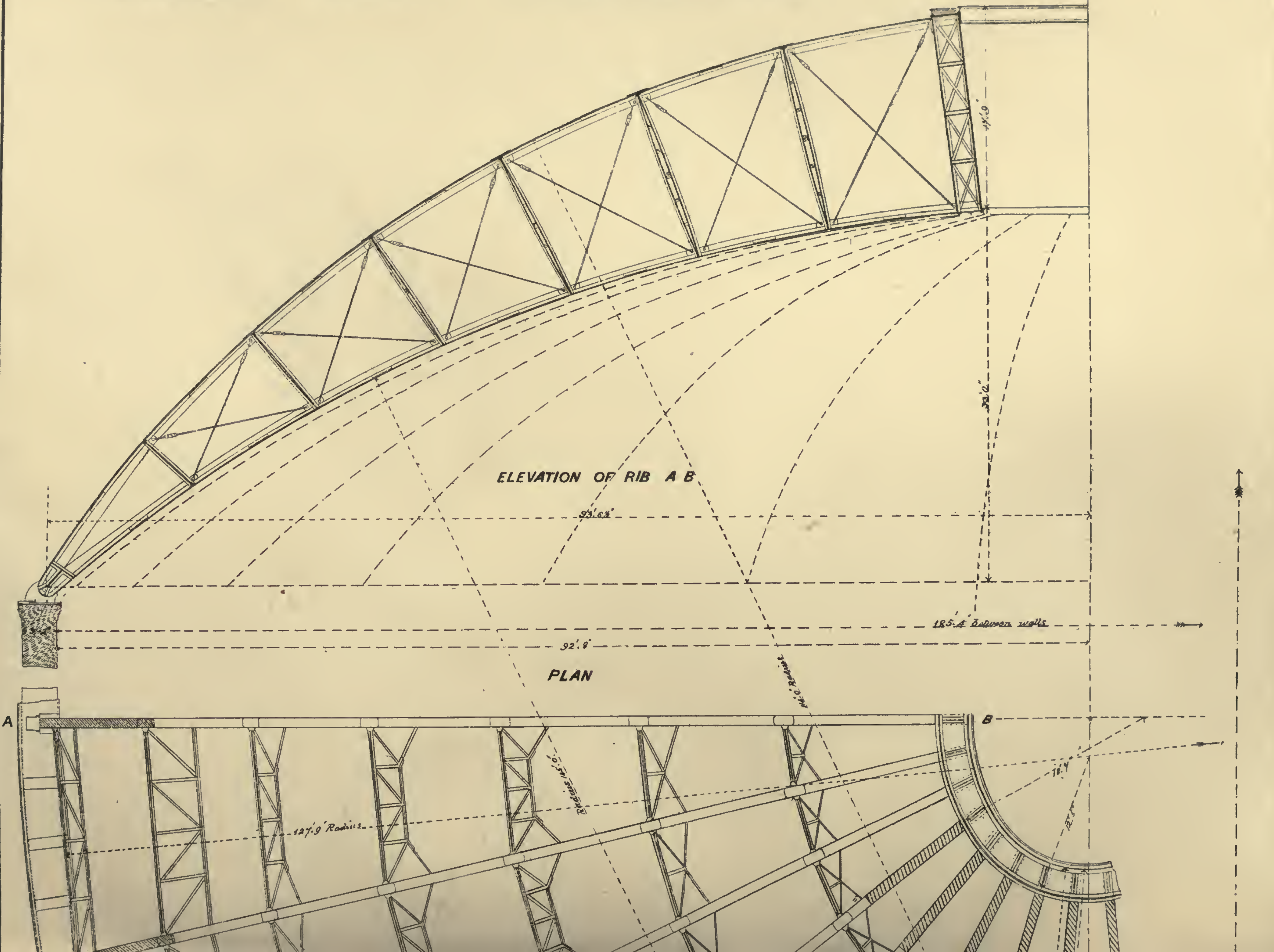

HALF ELEVATION OF CENTRE PRINCIPALS
ECTION OF
OP FLANGE
Line of top of L.I. over spandril
H
I
8.'0"
8.'0"
8.'0"
9.'6¾"
9.'0"
10.'9"
1.'9"
T.I. 6"×3"×½"
T.I. 5"×2½"×⅜"
T.I. 5"×2½"×⅜"
4 Bars { Two 4½"×⅜" Two 4½"×⅝"
4 Bars { Two 4"×⅜" Two 4"×⅝"
4 Bars { Two 3½"×⅜" Two 3½"×⅝"
L.I. 3½"×3½"×⅜"
L.I. 4½"×4"×½"
3½"×¾"
⅜"
5/16"
8.'1½"
7.'8"
7.'7"
7.'5"
Rad. 68.'0"
SCALE
INCHES 12 0 1 2 3 4 5 6 7 8 9 10 FEET
CENTIMETRES 100 50 0 1 2 3 MÈTRES
SIDE VIEW SHOWING PURLINS
SCALE
INCHES 12 0 5 10 15 20 25 30 35 40 45 50 FEET
Centimetres 100 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 Mètres
A
STREET LEVEL
46'-4"
109'-0"
109'-0"
44'-8"
SCALE
FEET 10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 FEET
Mètres 10 5 0 10 20 30 40 Mètres

ALBERT HALL KENSINGTON




CONNECTION OF PURLIN WITH MAIN RIB
A
...m Framework - for details see Plate Nº 59
SECTION AT AB.
A
B
3×3×5/16 L.I
ELEVATION OF RIB.
2½×2½×5/16 L.I
3×3×5/16 L.I
...IN AT A.
INSIDE ELEVATION OF UPPER CURB
SECTION OF UPPER CURB
a
a
SECTION AT a.a.
...f Shoe
5 6 7 8 9 10 Feet
1 2 Mètres
Inches 12 6 0 1 2 3 4 5 Feet
Scale for General Details
Centimetres 100 50 0 1 Mètre

ALBERT HALL KENSINGTON



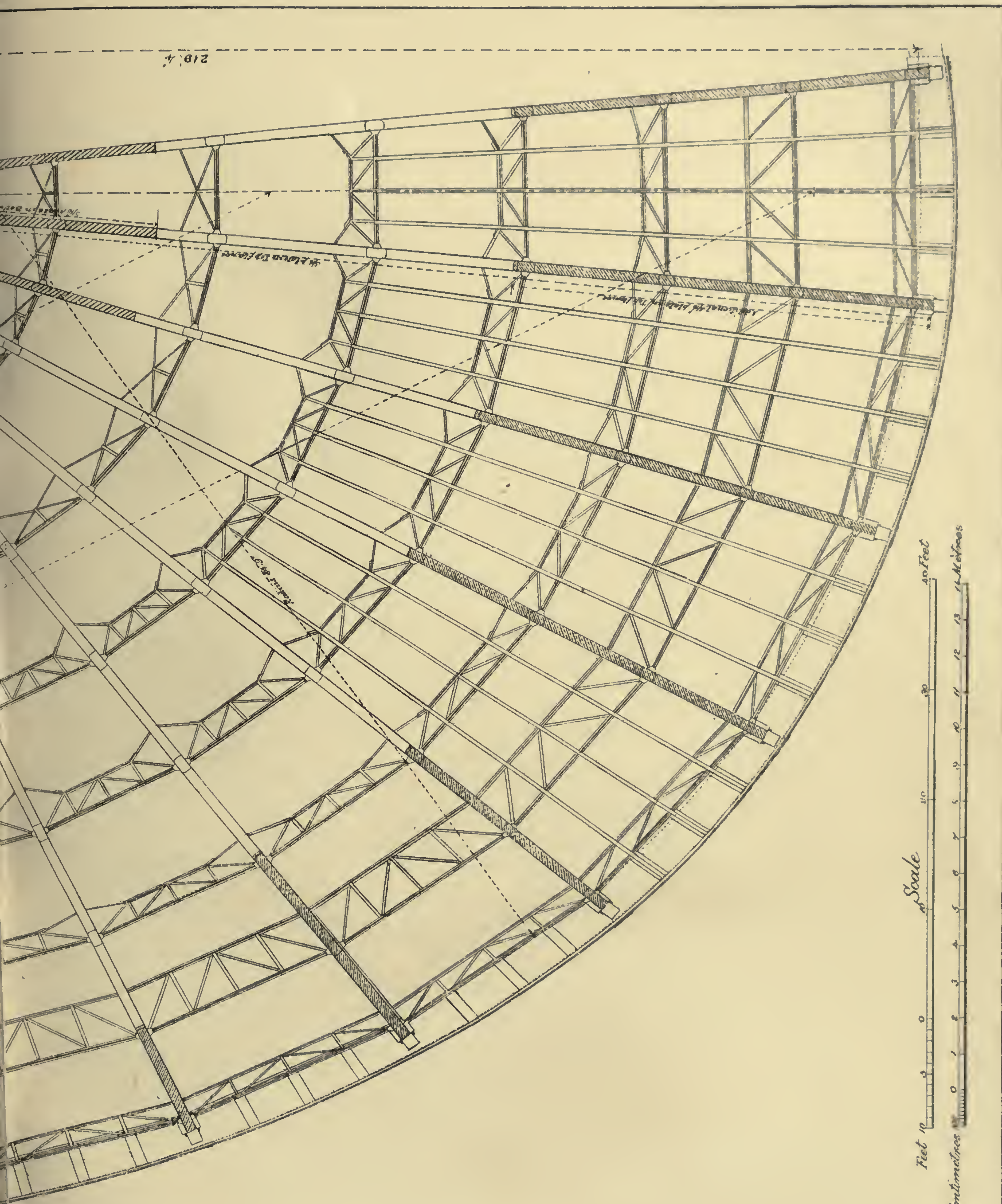
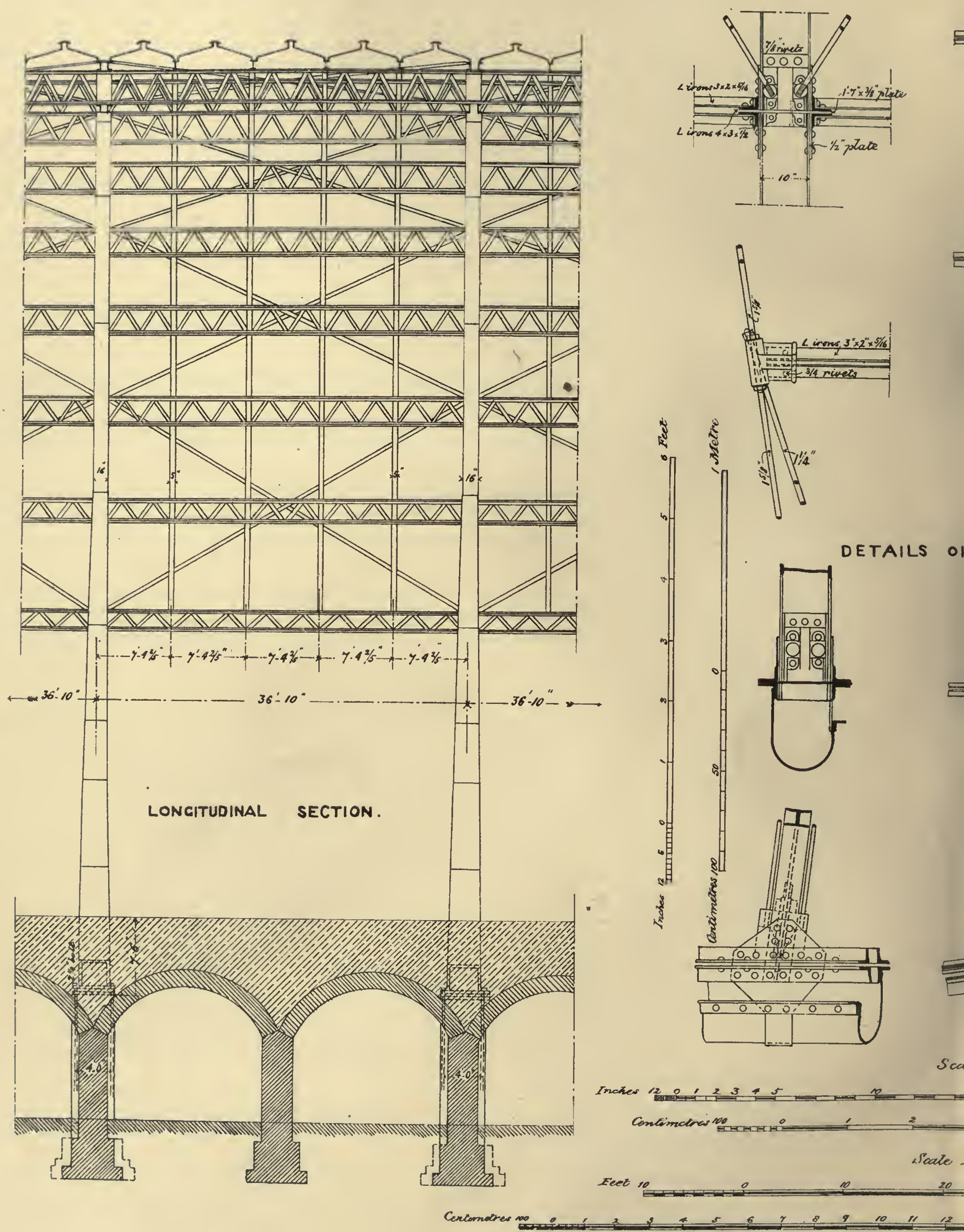


PHOTO-LITHO, SPRAGUE & Co. LONDON.

C. & S.W.R.
S^T ENOCH STATION GLASGOW



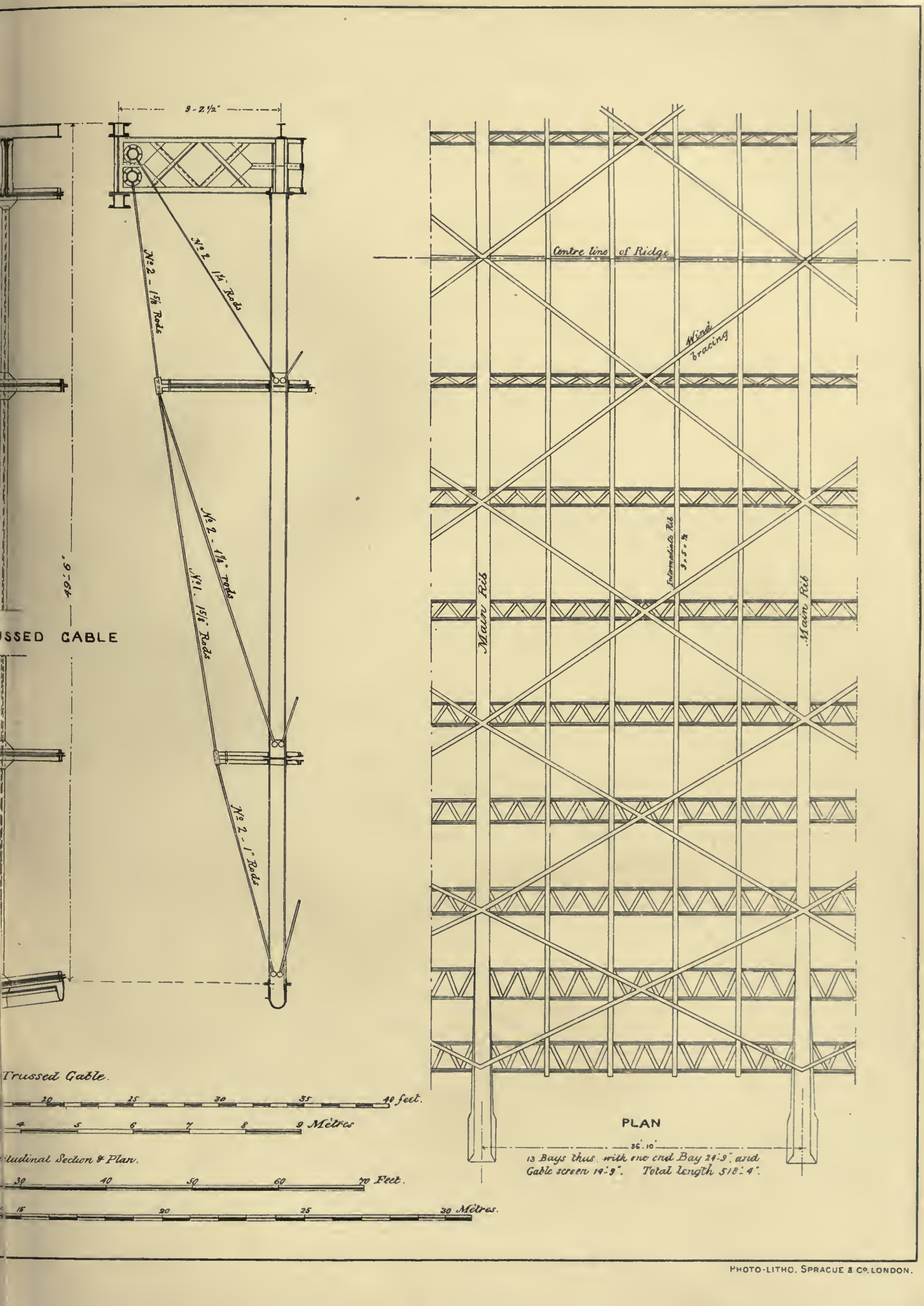
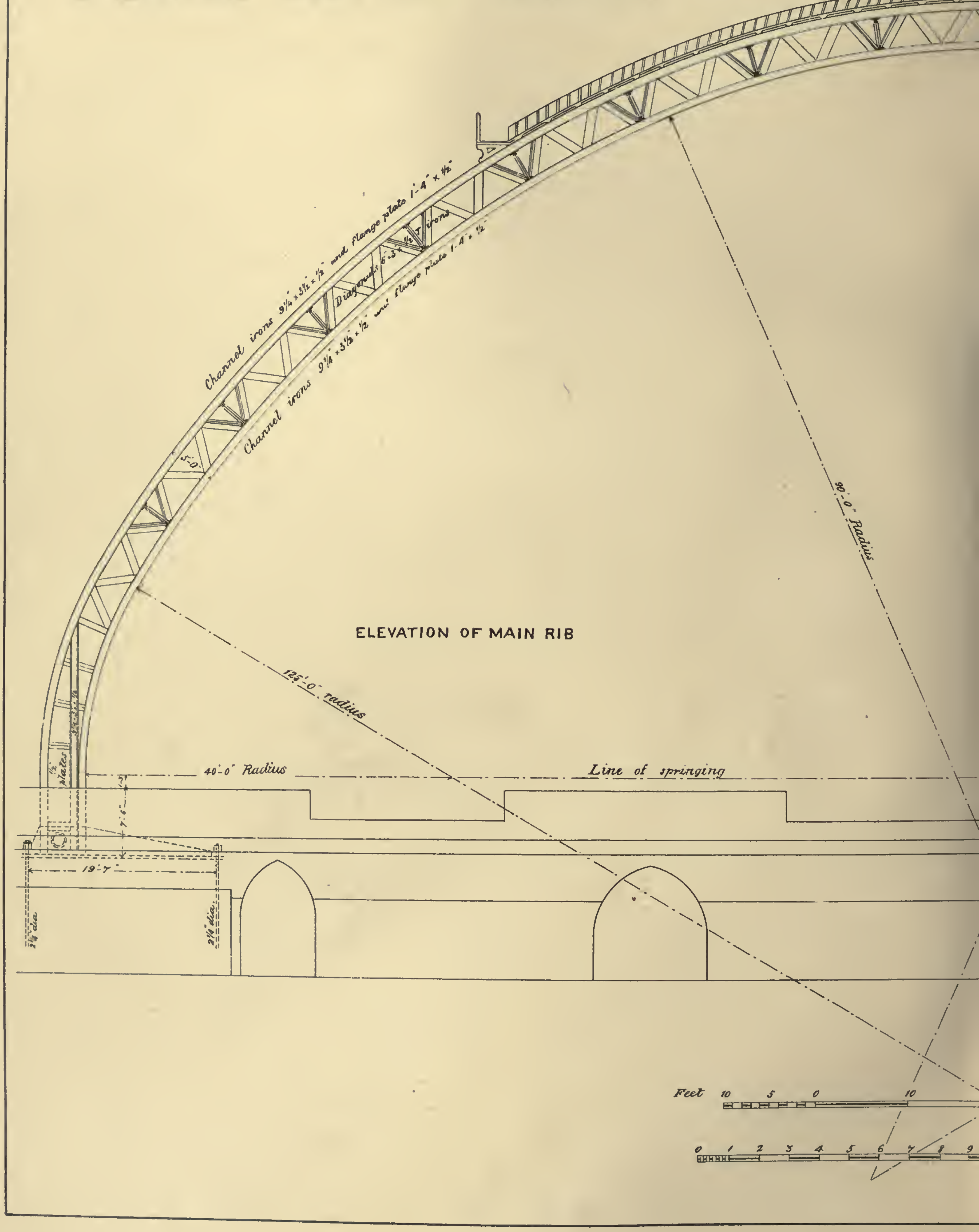
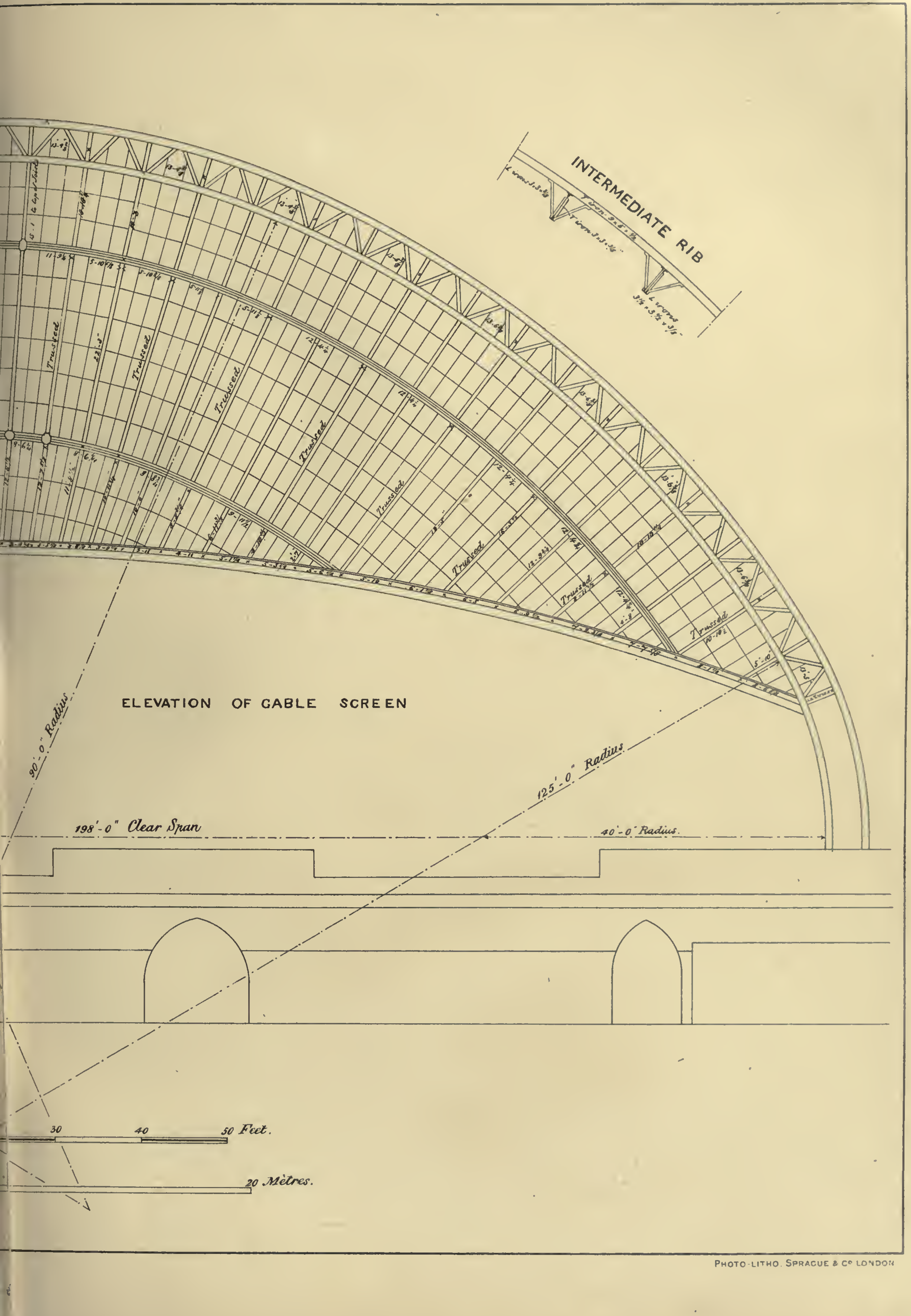


PHOTO-LITHO. SPRAGUE & Co. LONDON.

G.& S.W.R.
ST ENOCH STATION GLASGOW

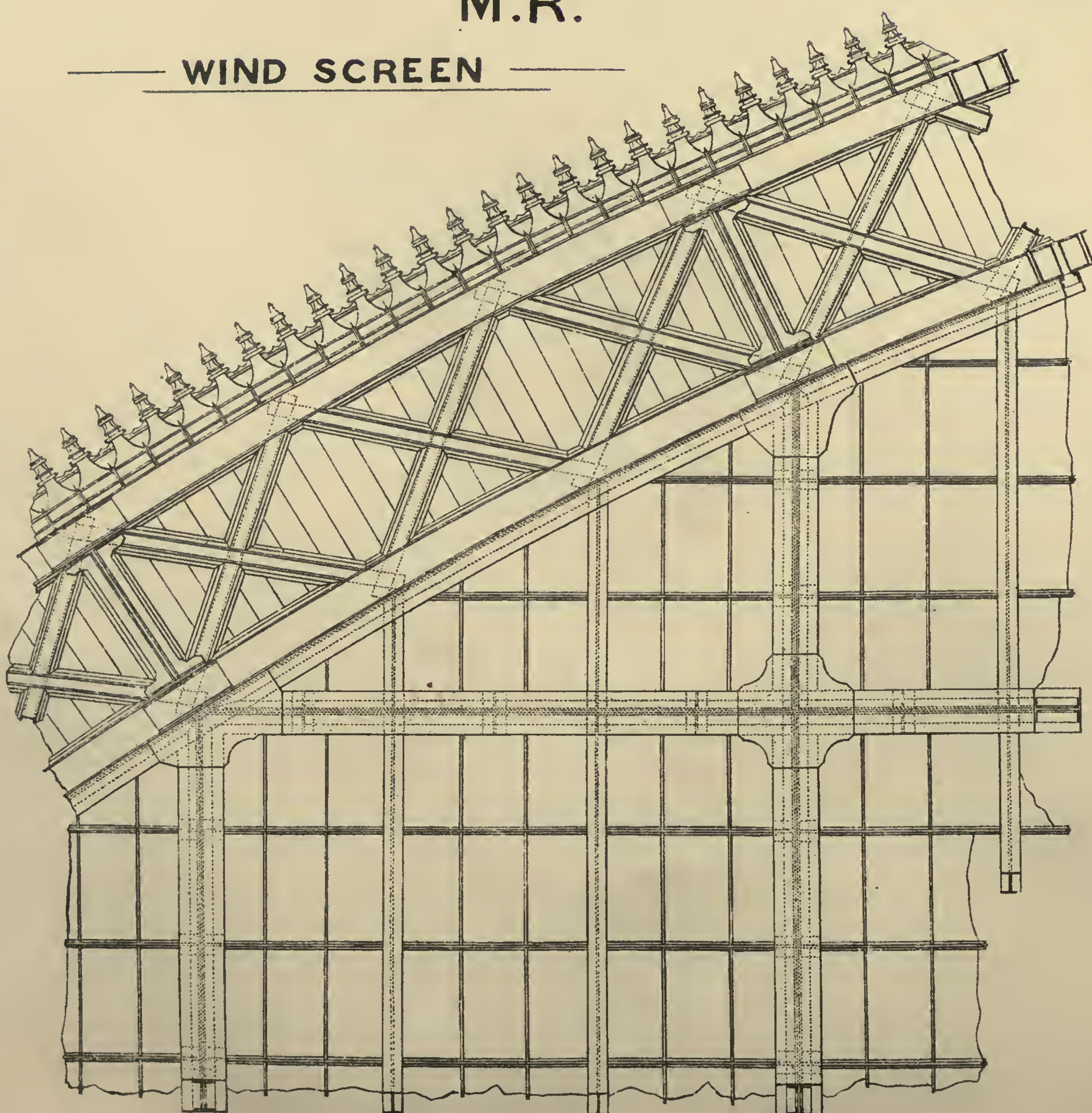


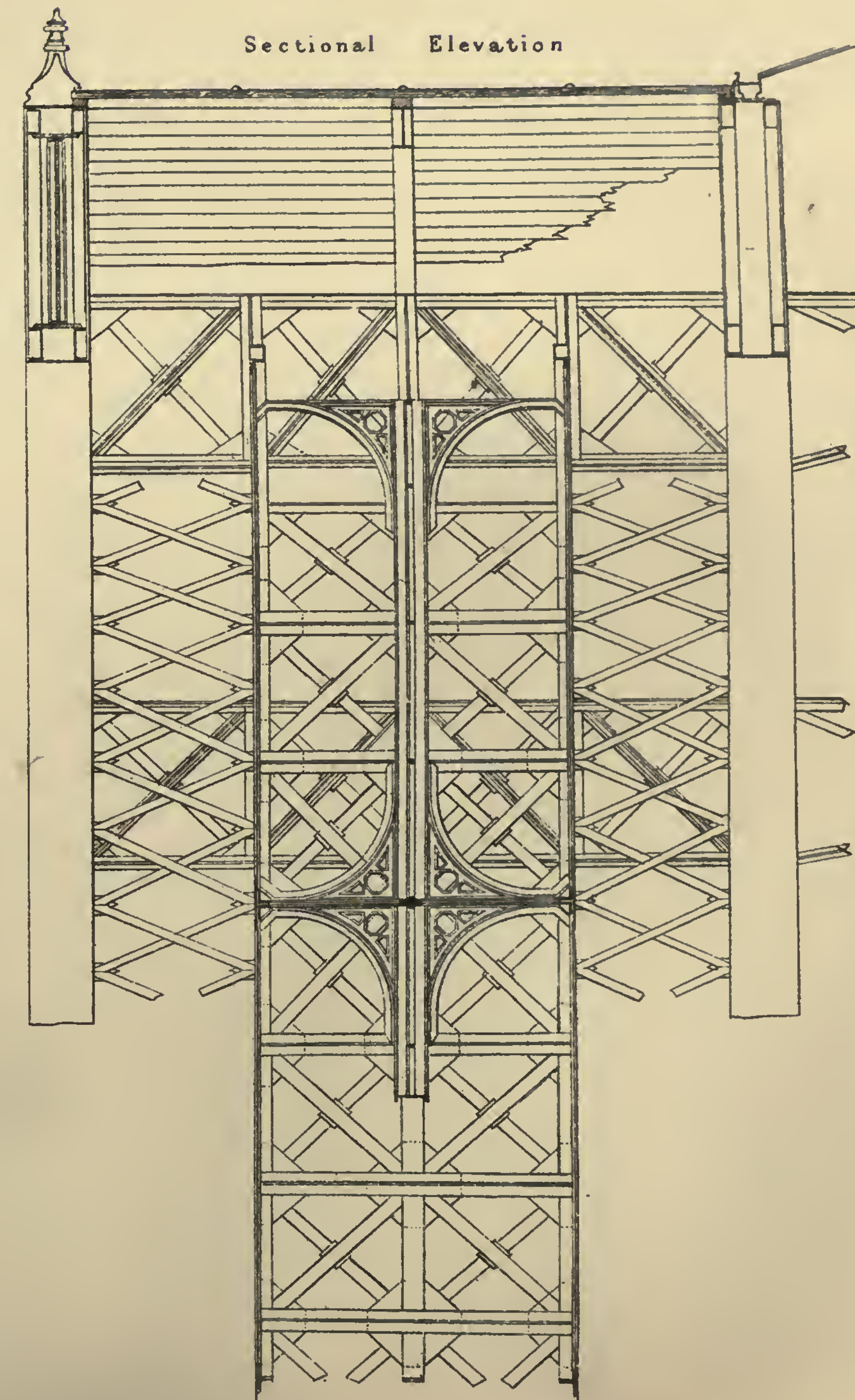

INTERMEDIATE RIB
ELEVATION OF GABLE SCREEN
90'-0" Radius
125'-0" Radius
198'-0" Clear Span
40'-0" Radius.
Trussed
30
40
50 Feet.
20 Mètres.

St PANCRAS STATION

M.R.

WIND SCREEN





SCALE

PLATE No. 56.

Centimetres 100 50 0 1 2 3 4 5 Mètres.

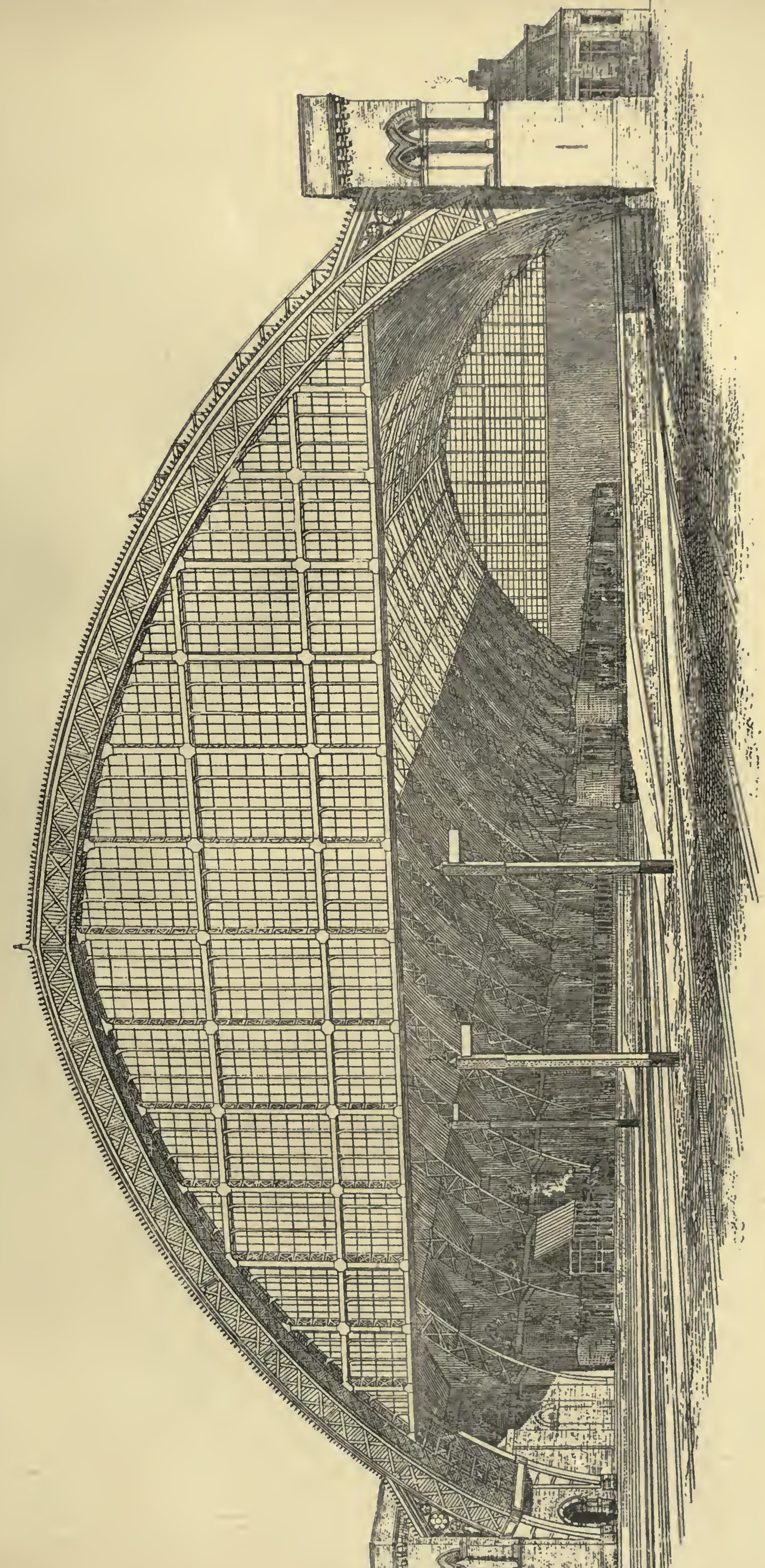
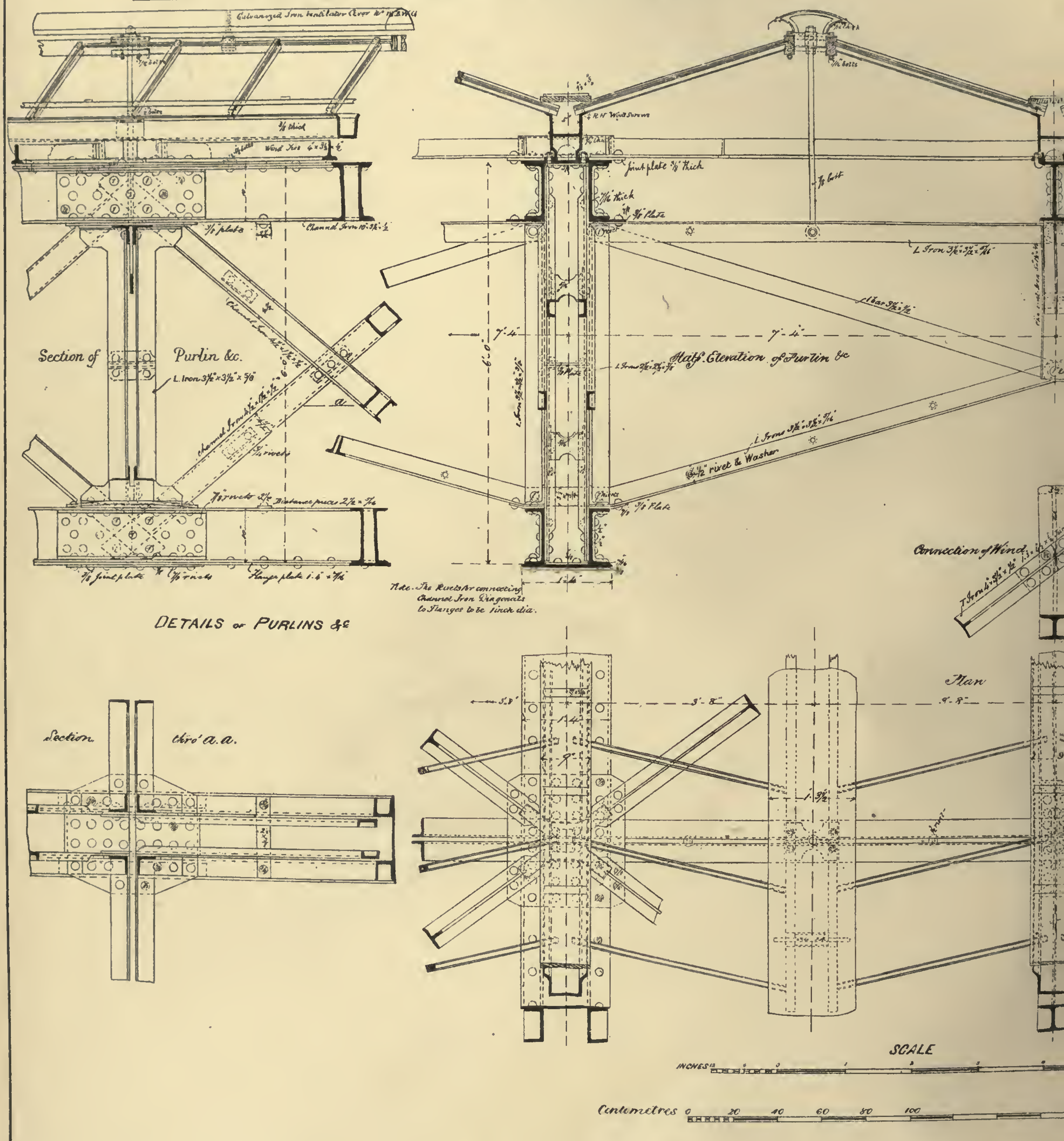


PHOTO-LITHO. SPRAGUE & Co. LONDON.

M.R.

St PANCRAS STATION



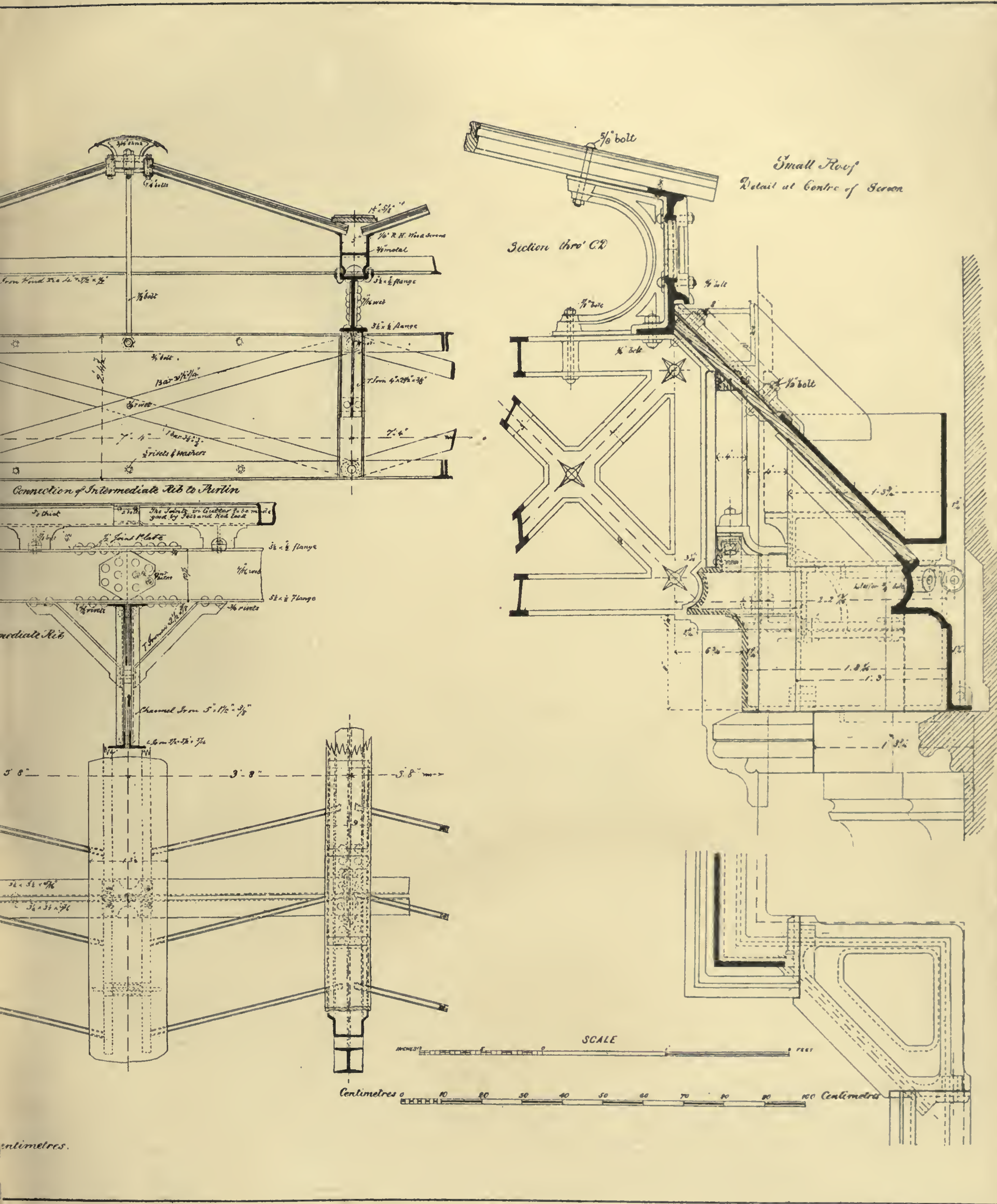
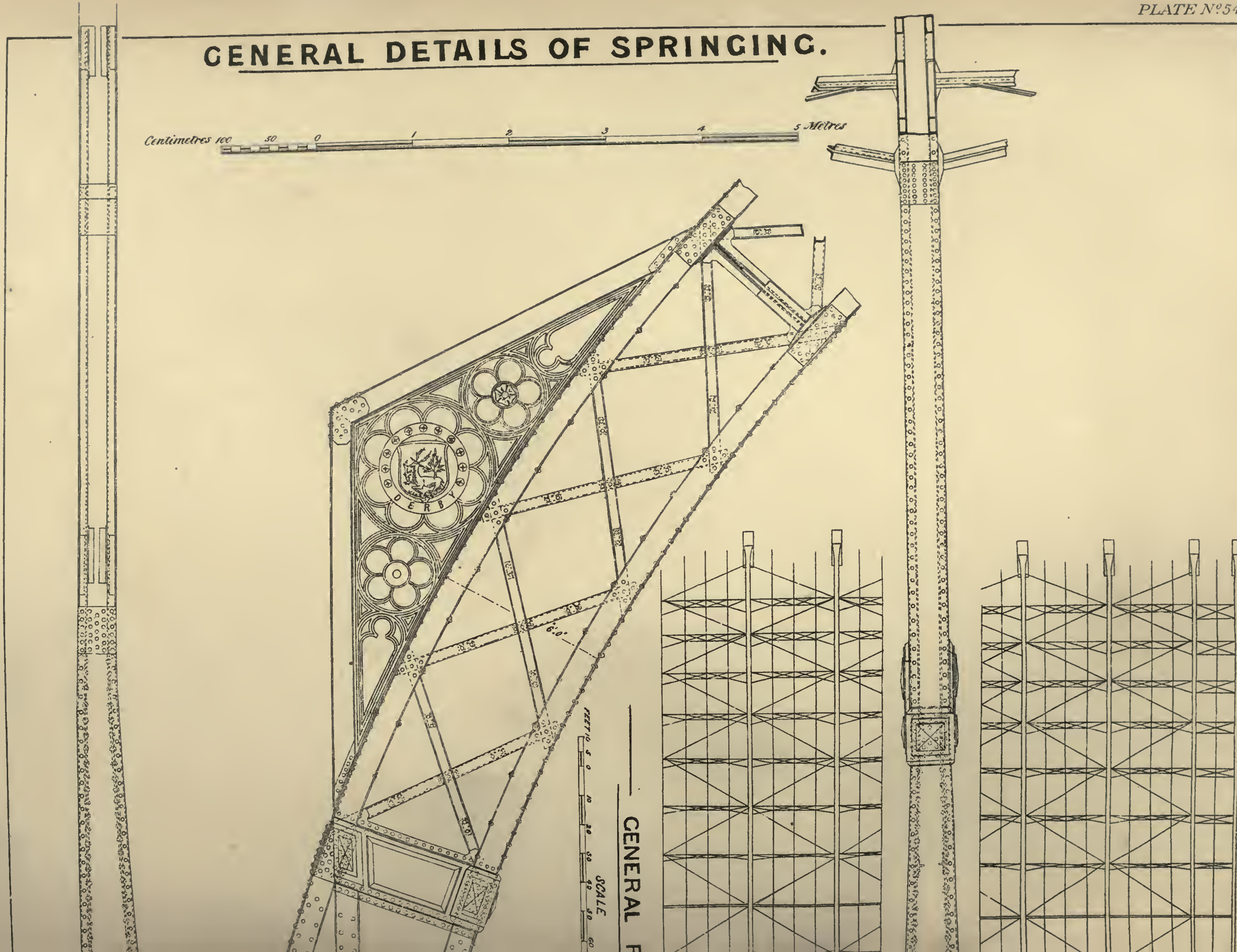


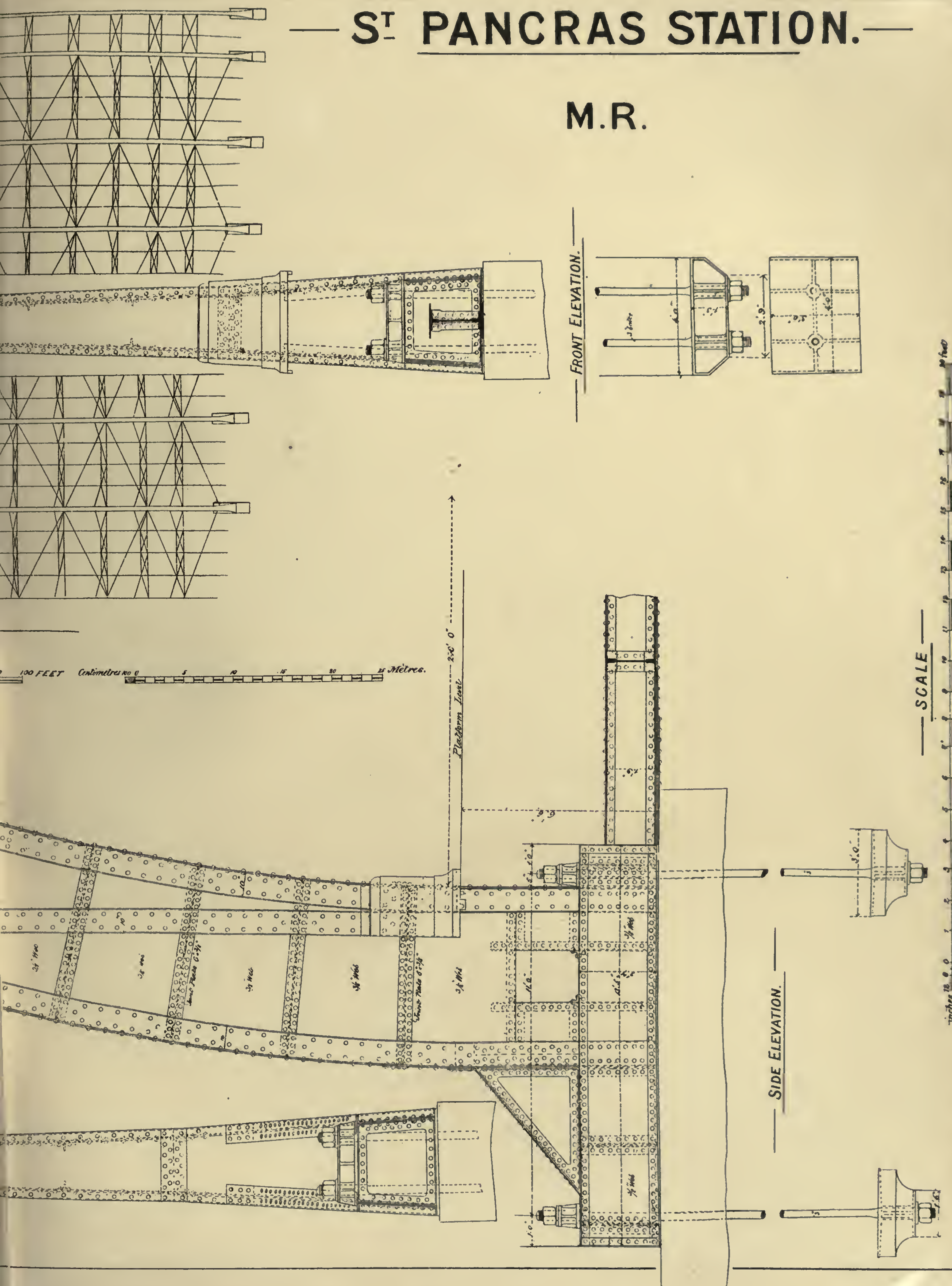
PHOTO-LITHO, SPRAGUE & Cº. LONDON.

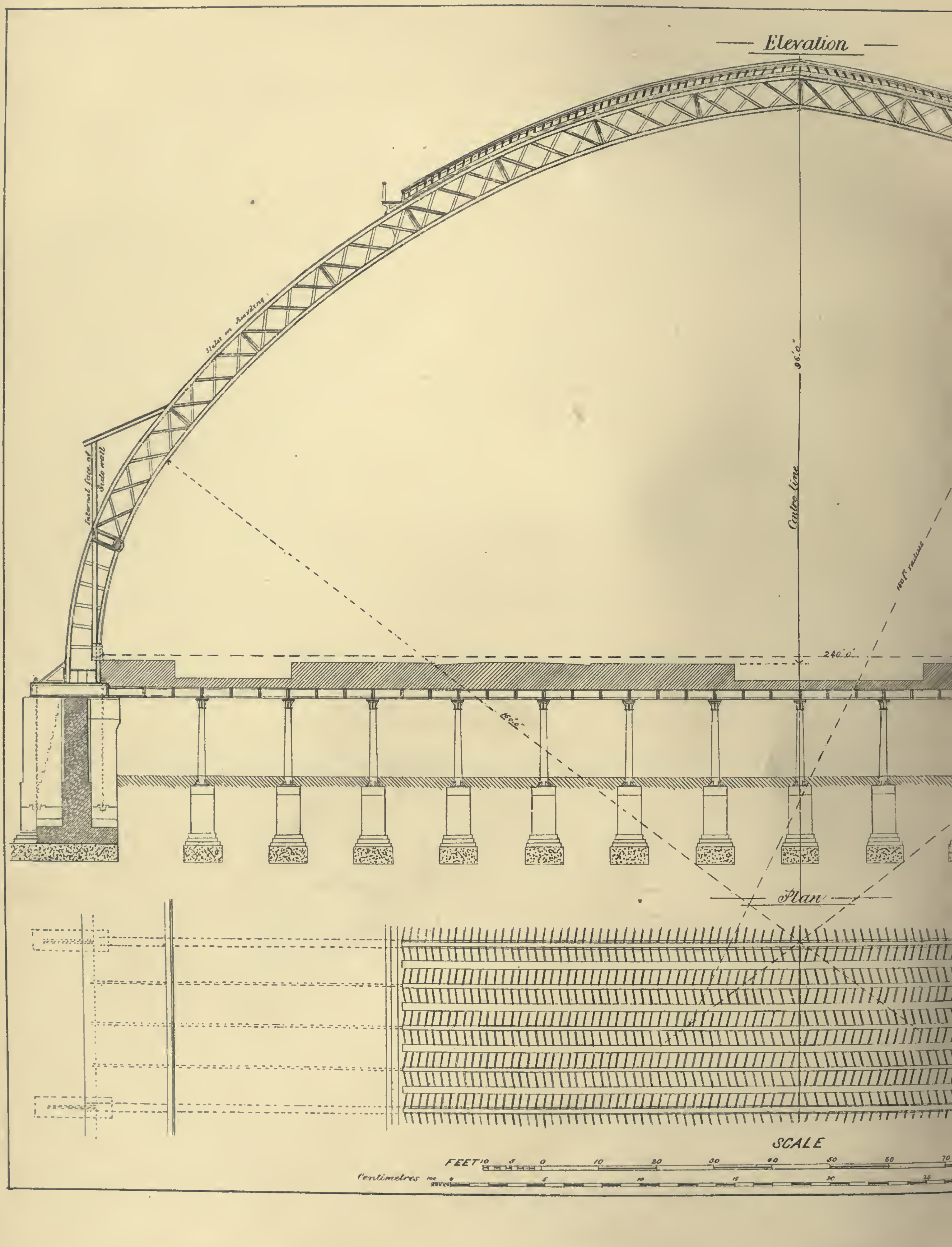
GENERAL DETAILS OF SPRINGING.



— St. PANCRAS STATION. —

M.R.





M. R.

ST PANCRAS STATION

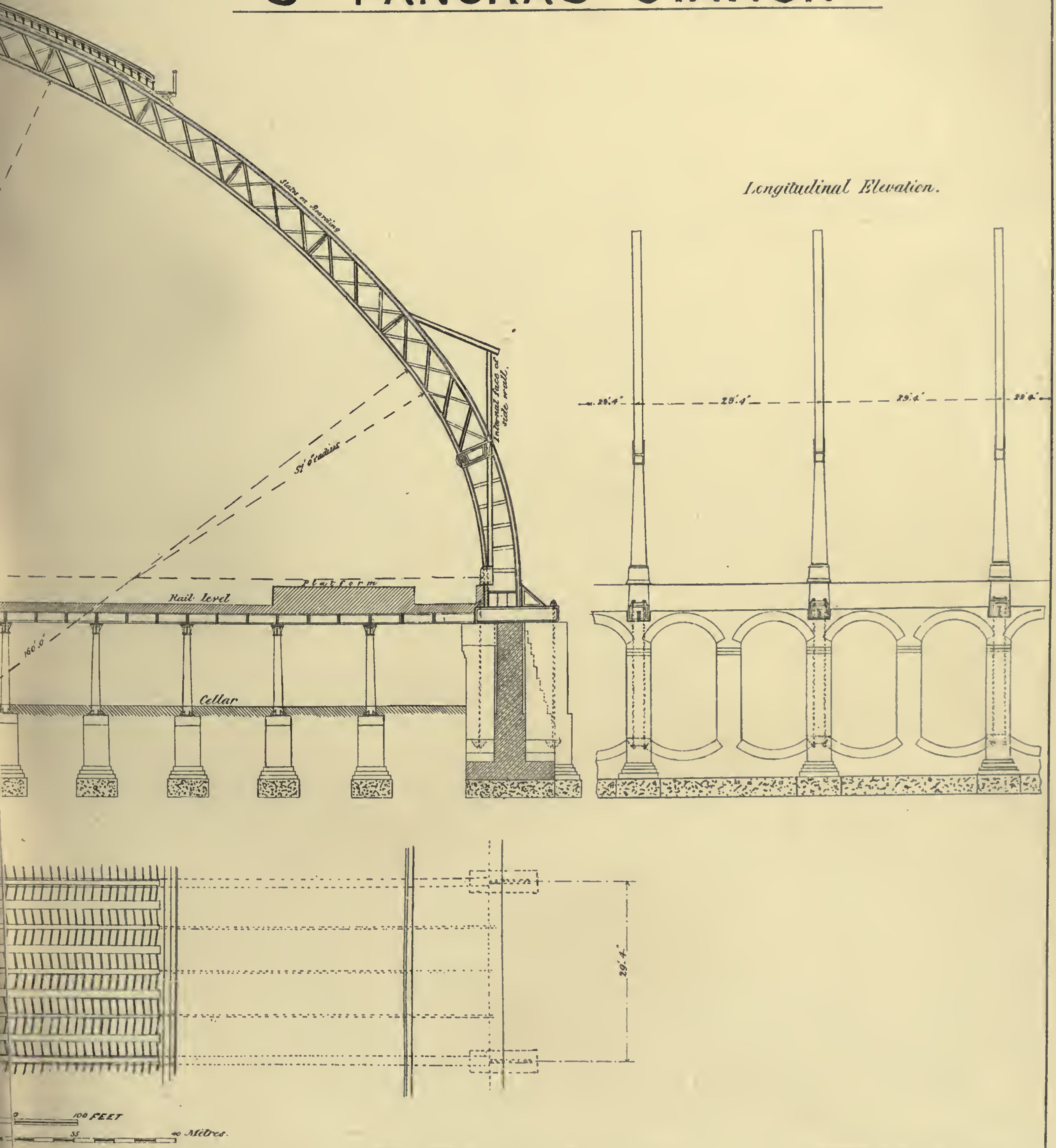
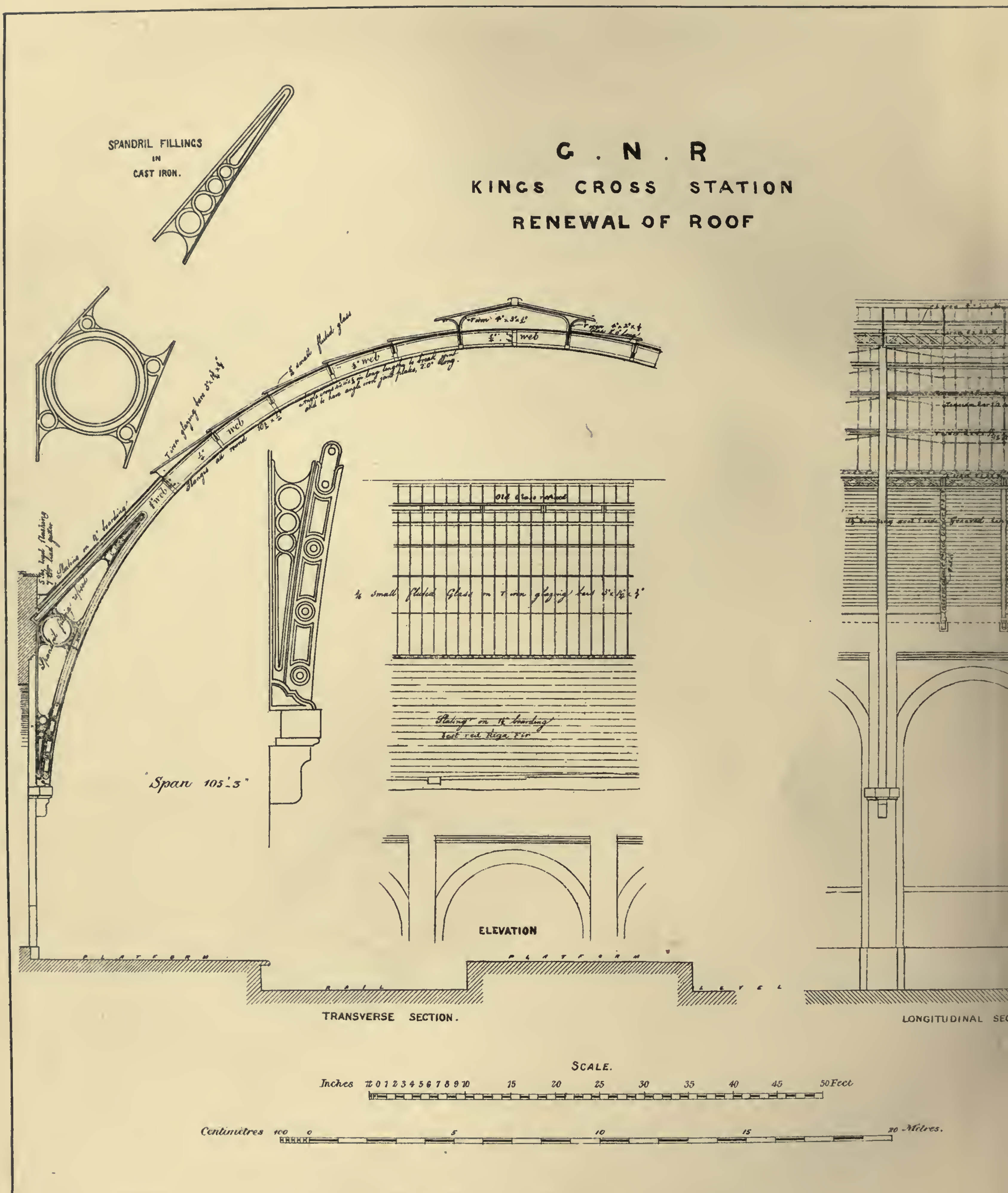
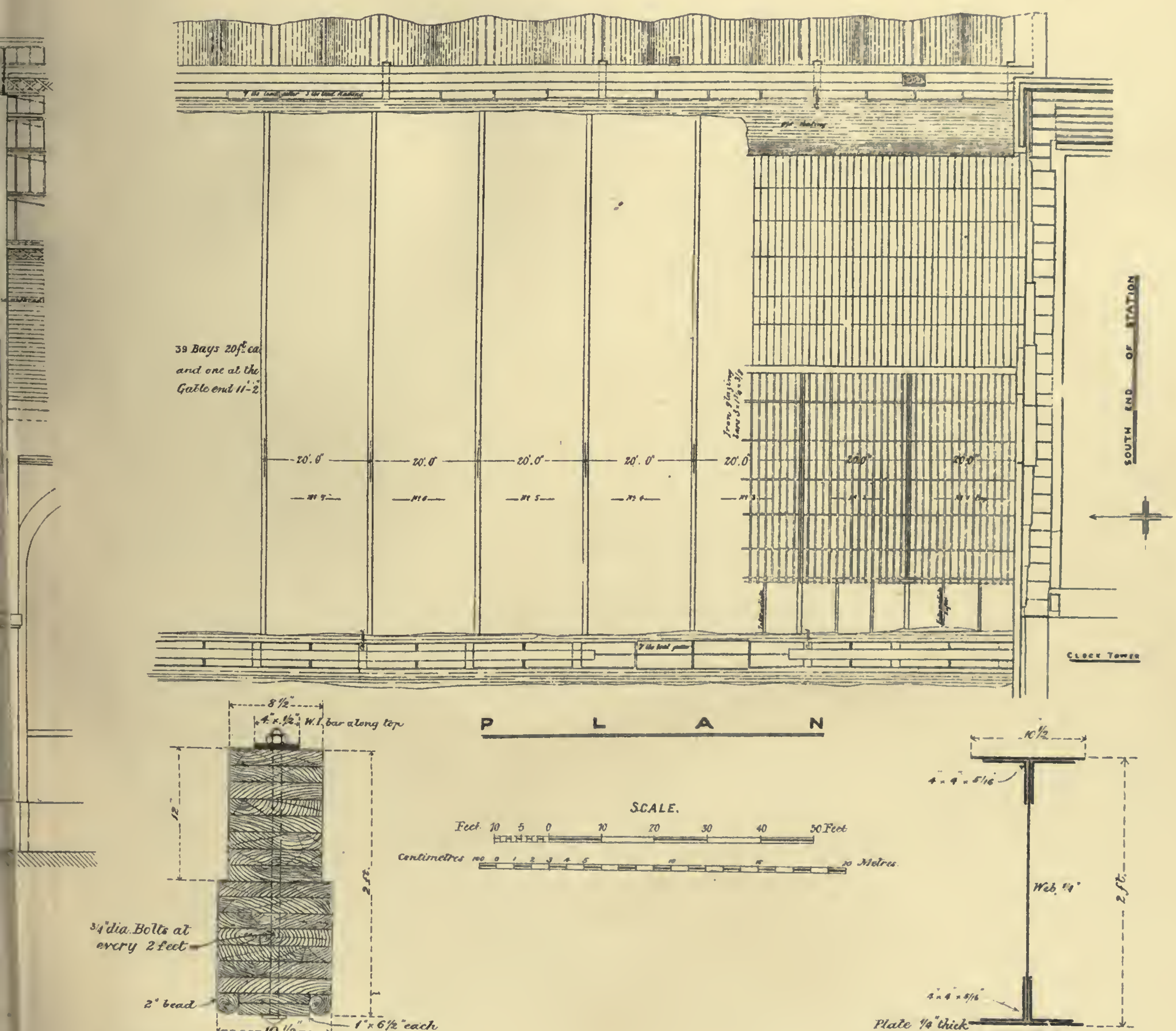


PHOTO-LITHO. SPRAGUE & Co. LONDON.


SPANDRIL FILLINGS IN CAST IRON.
G . N . R
KINGS CROSS STATION
RENEWAL OF ROOF
Span 105'-3"
ELEVATION
TRANSVERSE SECTION.
LONGITUDINAL
SCALE.
Inches 12 0 1 2 3 4 5 6 7 8 9 10 15 20 25 30 35 40 45 50 Feet
Centimètres 100 0 5 10 15 20 Mètres.

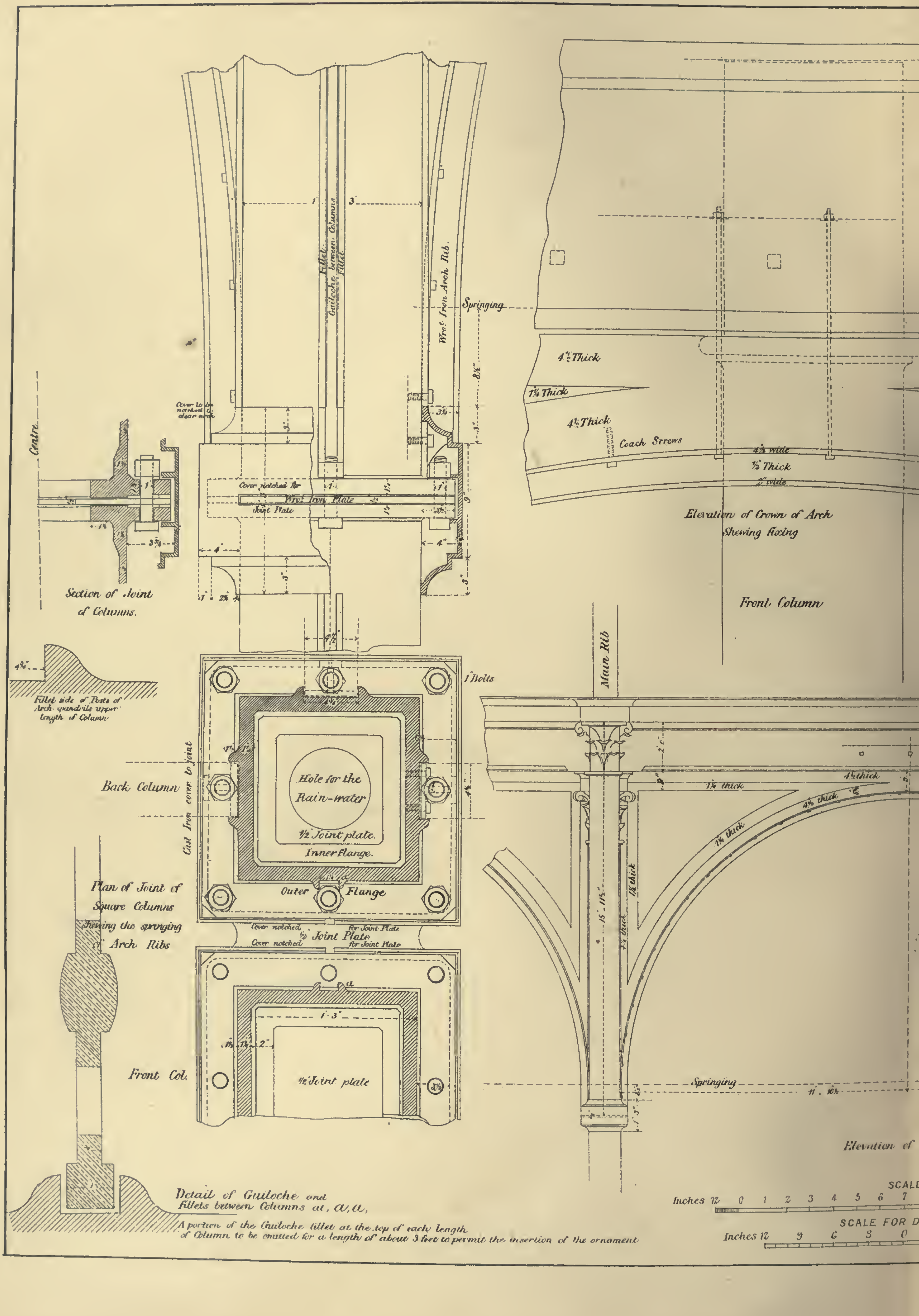
Note. The timber Roof in two spans was built in the year 1851.
The iron Roof over the eastern Arcade (arrival Platforms) was erected in the year 1869.
and the iron Roof over the western Arcade (departure Platforms) was erected in the year 1887.



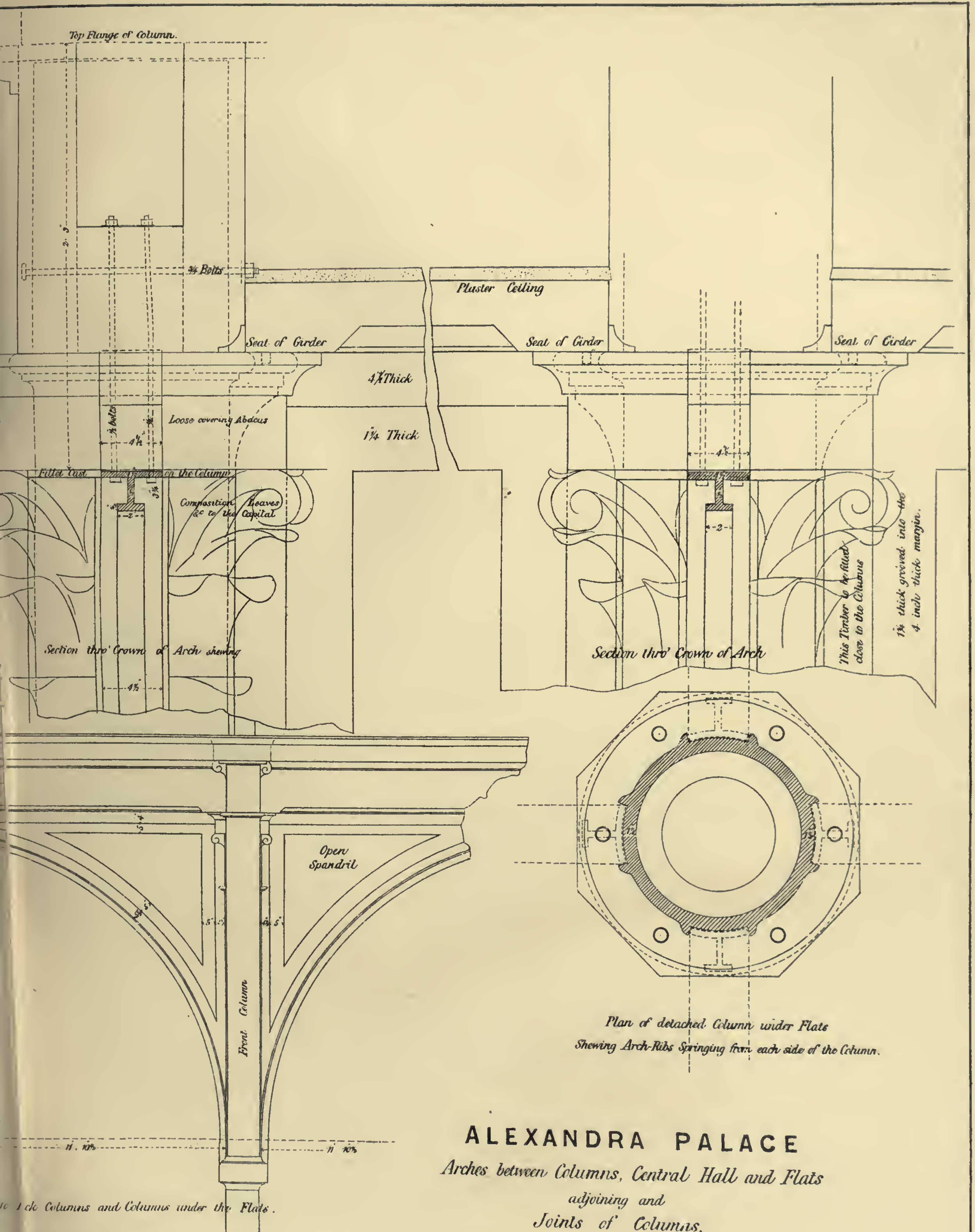
Section of Timber built Main Rib of old Station roof.

Section of wrought iron rib.

PHOTO-LITHO. SPRAGUE & C°. LONDON



Fillet
Guiloche between Columns
Fillet
Wrot. Iron Arch Rib.
Springing
Cover to be notched to clear arch
Centre
Cover notched for
Wrot. Iron Plate
Joint Plate
Section of Joint of Columns.
4½ Thick
1¼ Thick
4½ Thick
Coach Screws
4½ wide
½ Thick
2" wide
Elevation of Crown of Arch Shewing fixing
Front Column
Main Rib
1" Bolts
Fillet side of Posts of Arch spandrils upper length of Column
Back Column
Cast Iron cover to joint
Hole for the Rain-water
½ Joint plate.
Inner flange.
Outer Flange
Plan of Joint of Square Columns Shewing the springing of Arch Ribs
Cover notched
½ Joint Plate
For Joint Plate
Cover notched
For Joint Plate
Front Col.
½ Joint plate
4½ thick
1¼ thick
4½ thick
1¼ thick
1¼ thick
1¼ thick
Springing
Elevation of
Detail of Guiloche and fillets between Columns at, a, a,
A portion of the Guiloche fillet at the top of each length of Column to be omitted for a length of about 3 feet to permit the insertion of the ornament
SCALE
Inches 12 0 1 2 3 4 5 6 7
SCALE FOR D
Inches 12 9 6 3 0



...le Columns and Columns under the Flats.

ALEXANDRA PALACE

Arches between Columns, Central Hall and Flats adjoining and Joints of Columns.

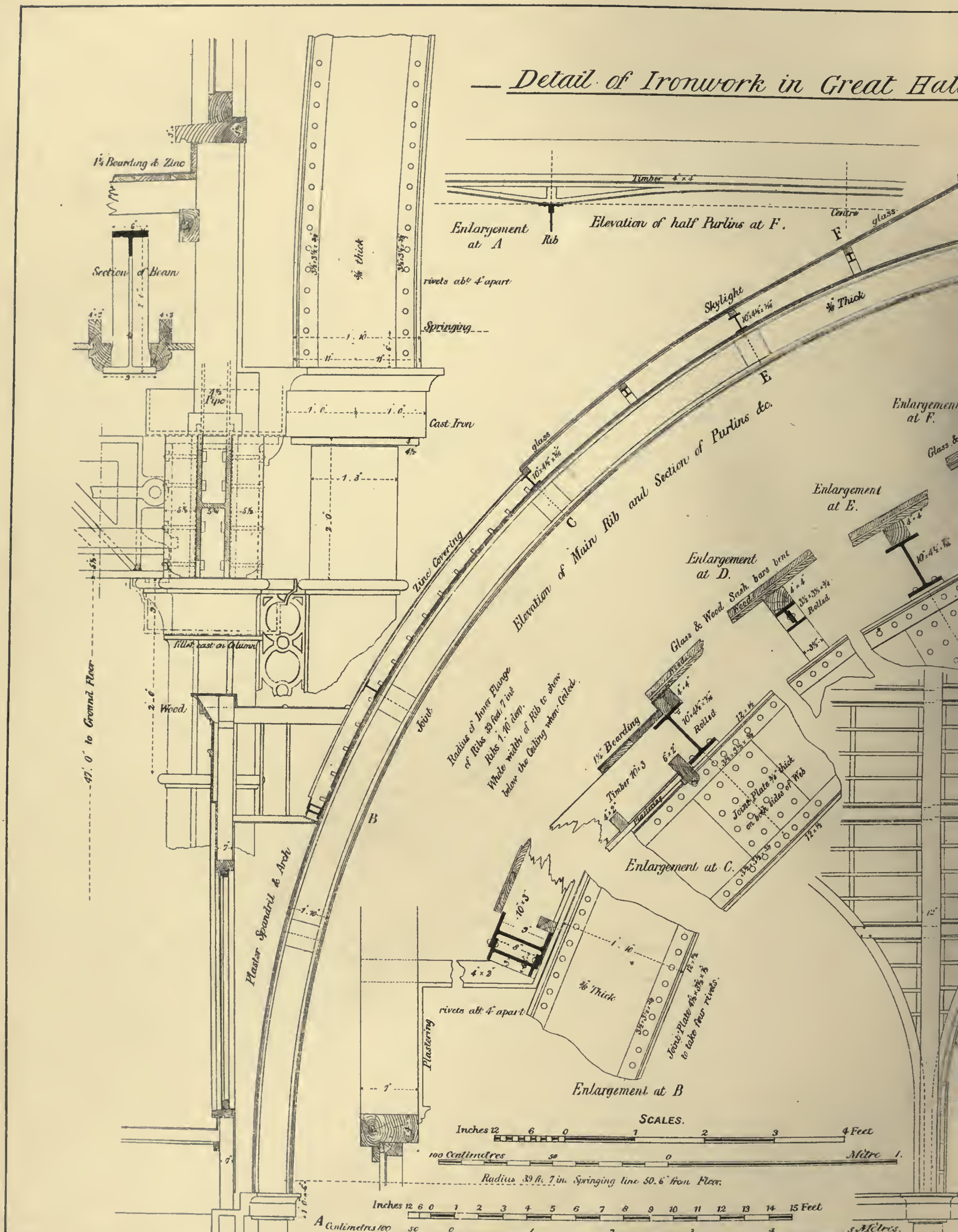
Centimetres 100 50 0 1 2 3 4 Mètres.

Centimetres 0 10 20 40 60 80 100 Centimetres.

10 11 12 13 14 15 Feet

1 Feet

PHOTO-LITHO. SPRAGUE & Co LONDON.



Detail of Ironwork in Great Hal
Timber 4" x 4"
Enlargement at A
Rib
Elevation of half Purlins at F.
Centre
glass.
F
1¼ Bearding & Zinc
Section of Beam
⅜ thick
rivets abt 4" apart
Springing
Skylight
⅜ Thick
E
Pipe
Cast Iron
Elevation of Main Rib and Section of Purlins &c.
Enlargement at F.
Glass &
Enlargement at E.
glass
Zinc Covering
C
Enlargement at D.
Glass & Wood Sash bars bent
Rolled
Fillet cast on Column
Wood
Joint
Radius of Inner Flange of Ribs 39 feet 7 ins.
Ribs 1' 10" deep.
Whole width of Rib to shew below the Ceiling when Ceiled.
1½ Bearding
Timber 4½ x 3
Joint Plate ⅜ thick on both sides of Web
47' 0" to Ground Floor
B
Enlargement at C.
Plaster Spandril & Arch
⅜ Thick
rivets abt 4" apart
Plastering
Joint Plate to take four rivets.
Enlargement at B
SCALES.
Inches 12 6 0 1 2 3 4 Feet
100 Centimetres 50 0 Metre 1.
Radius 39 ft. 7 in. Springing line 50. 6" from Floor.
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet
A
Centimetres 100 50 0 1 2 3 4 5 Metres.

ALEXANDRA PALACE.

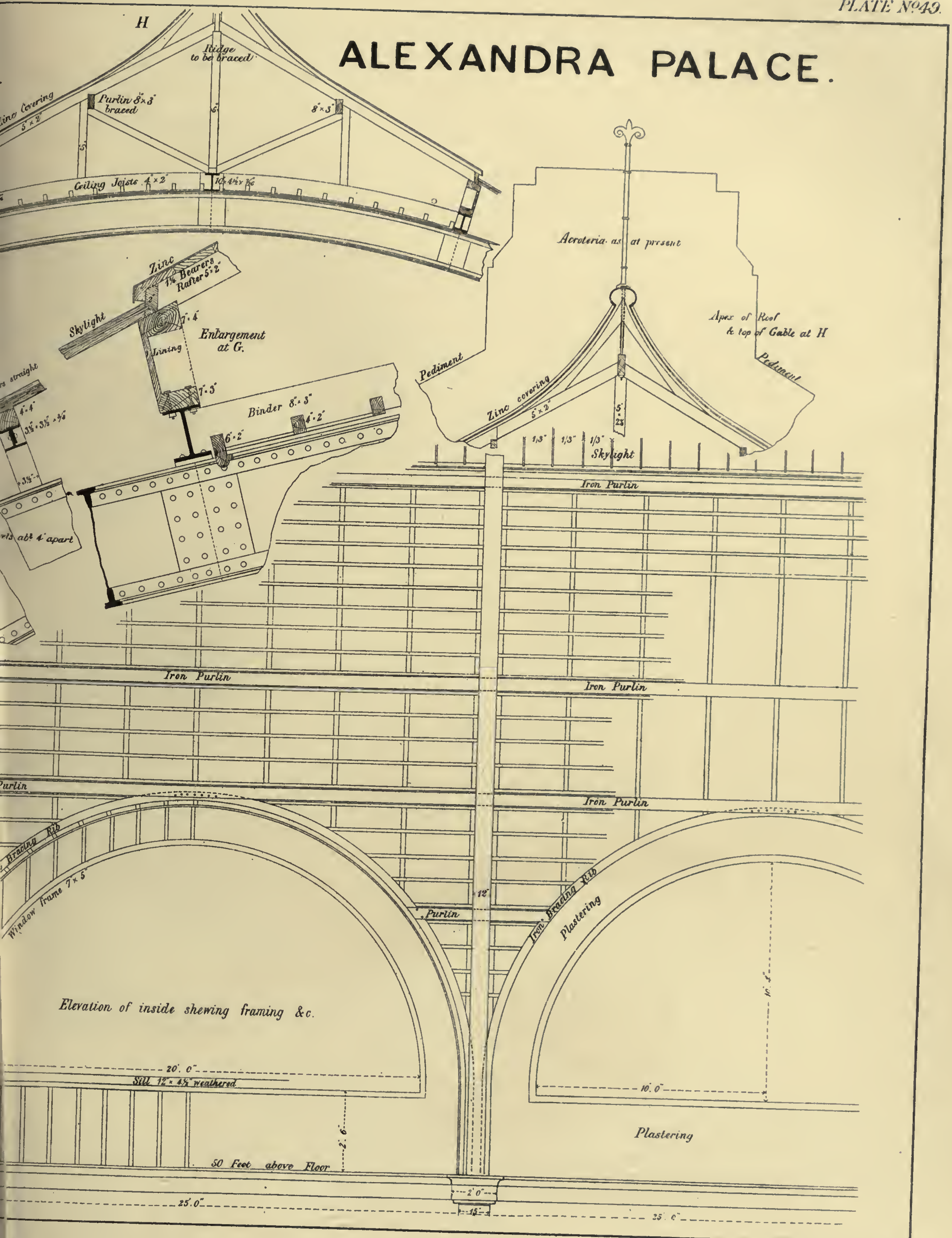
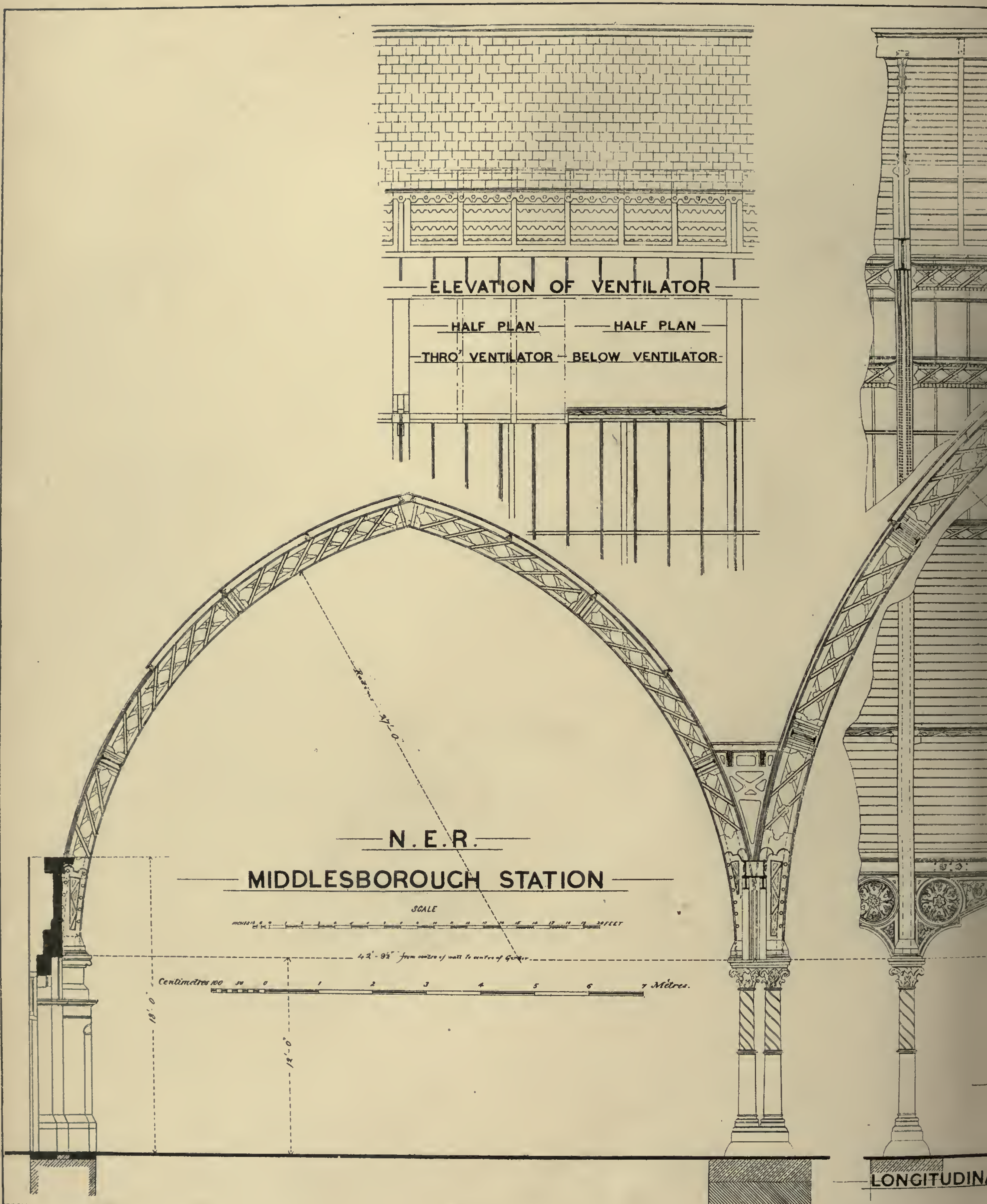


PHOTO-LITHO. SPRAGUE & Cº. LONDON.


ELEVATION OF VENTILATOR
HALF PLAN
THRO' VENTILATOR
HALF PLAN
BELOW VENTILATOR
Radius 37'-0"
N.E.R.
MIDDLESBOROUCH STATION
SCALE
INCHES 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 FEET
42'-9½" from centre of wall to centre of Girder
Centimetres 100 50 0 1 2 3 4 5 6 7 Métres.
18'-0"
12'-0"
LONGITUDIN

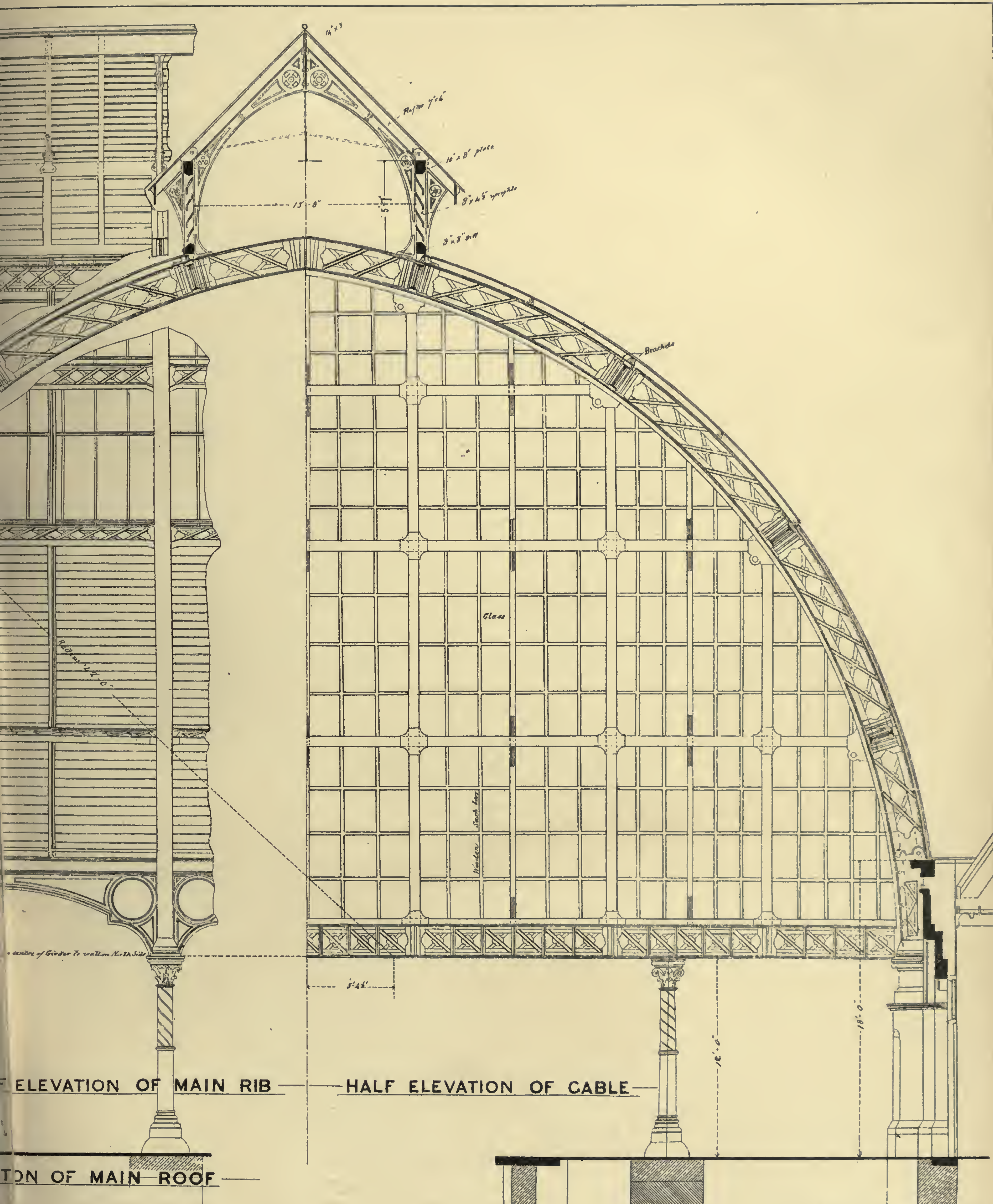


PHOTO-LITHO, SPRAGUE & Co. LONDON.

PRESTON STATION L.& N.W.R.

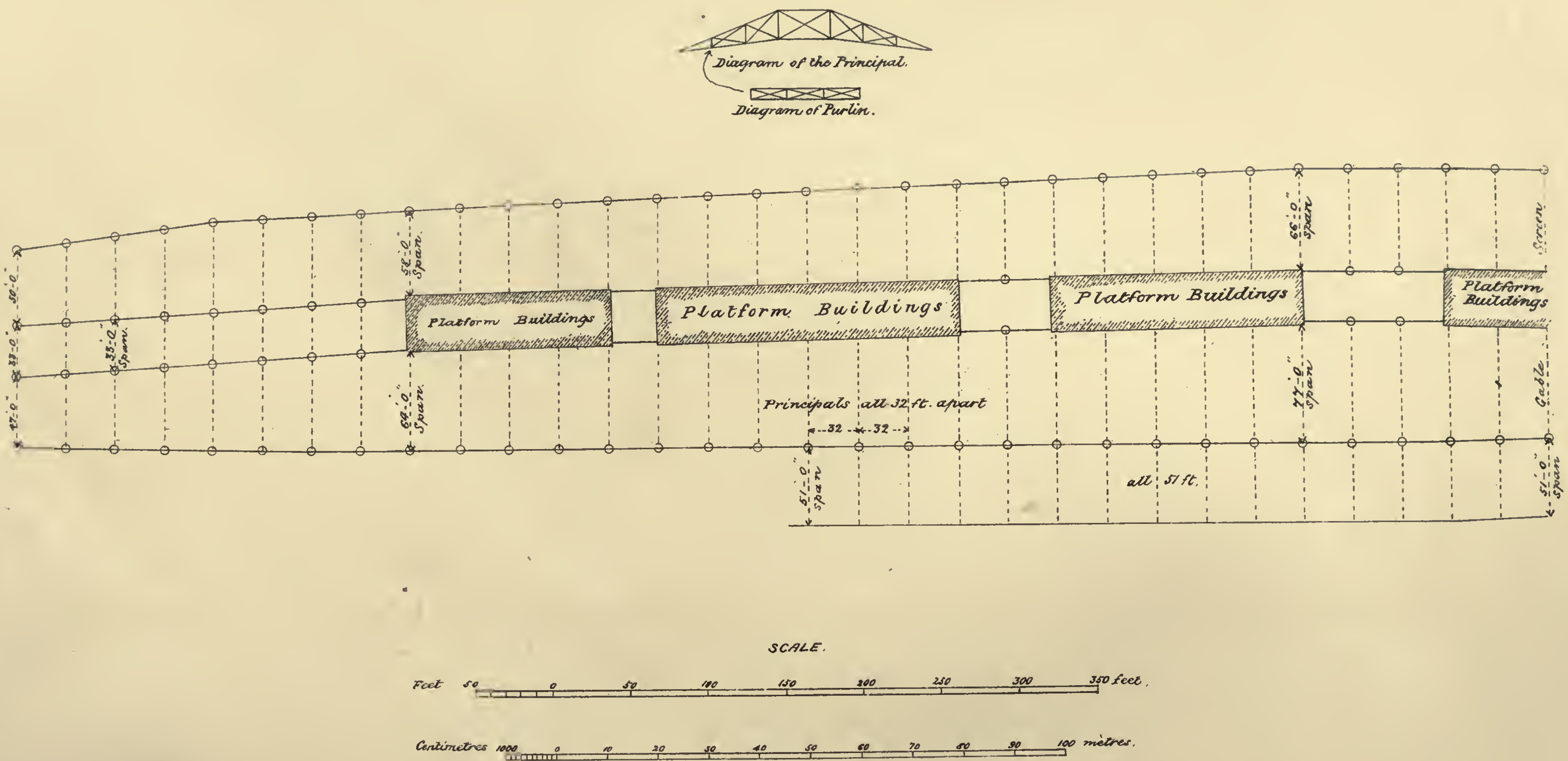


PHOTO-LITHO. SPRAGUE & Co. LONDON.

PLATE No. 47.

N. E. R.

MIDDLESBOROUGH STATION

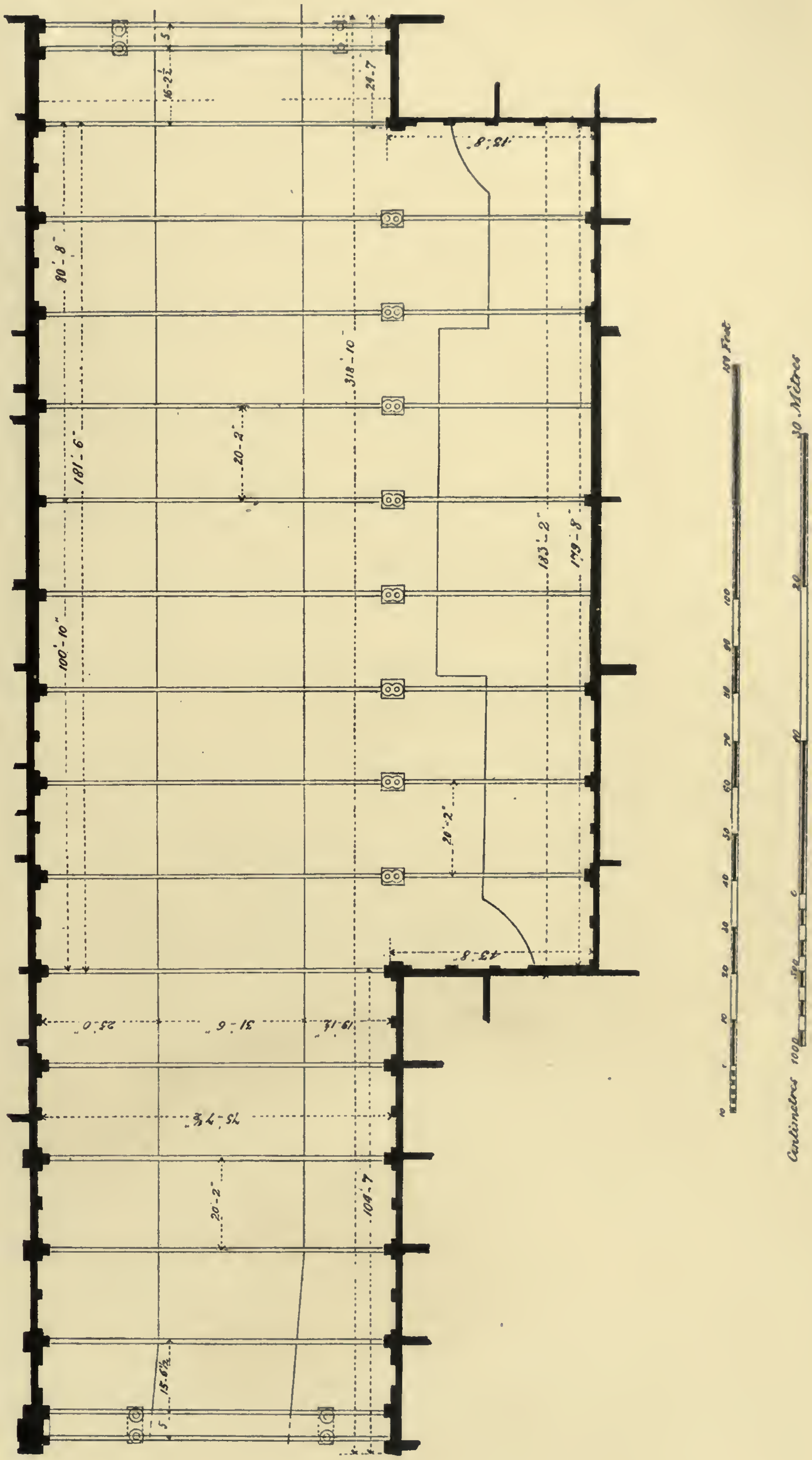
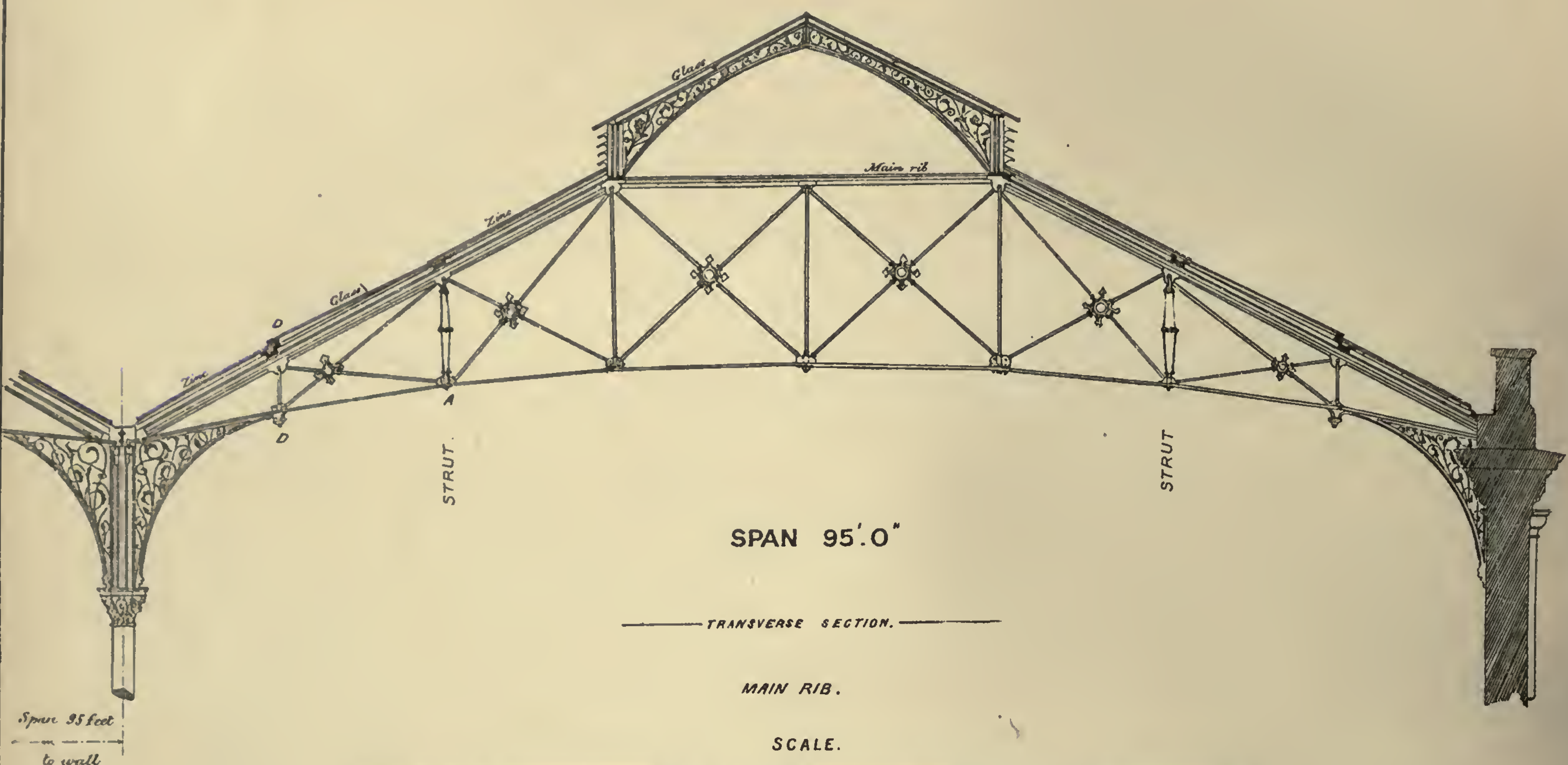


Photo-Litho. Sprague & Co London.

BROAD STREET STATION LONDON. N.L.R.



SPAN 95'.0"

TRANSVERSE SECTION.

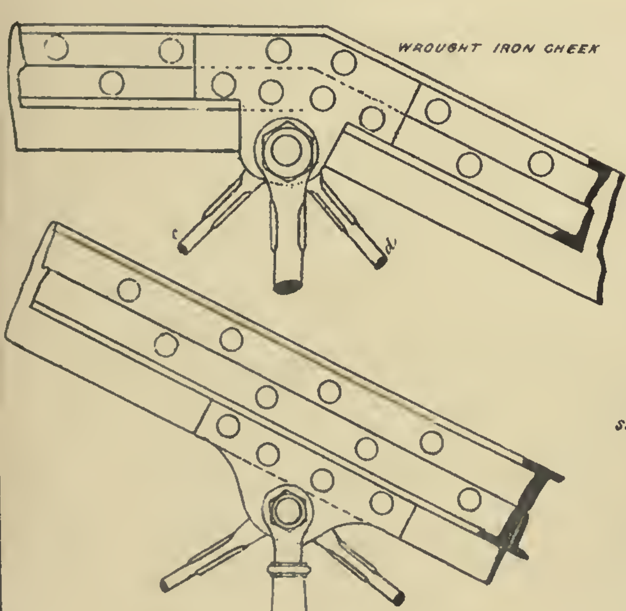
MAIN RIB.

SCALE.

10 5 0 10 20 30 40 50

Centimetres 100 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Mètres.

FIG. 2.

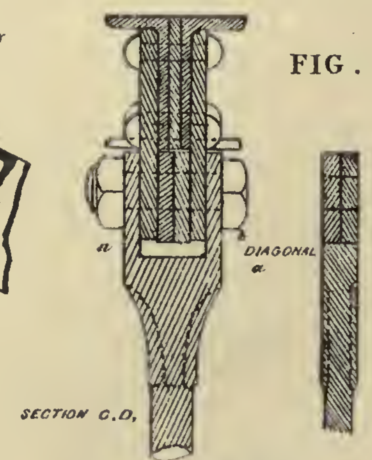


SCALE FOR FIG 2.

Inches 12 9 6 3 0 1 2 Feet

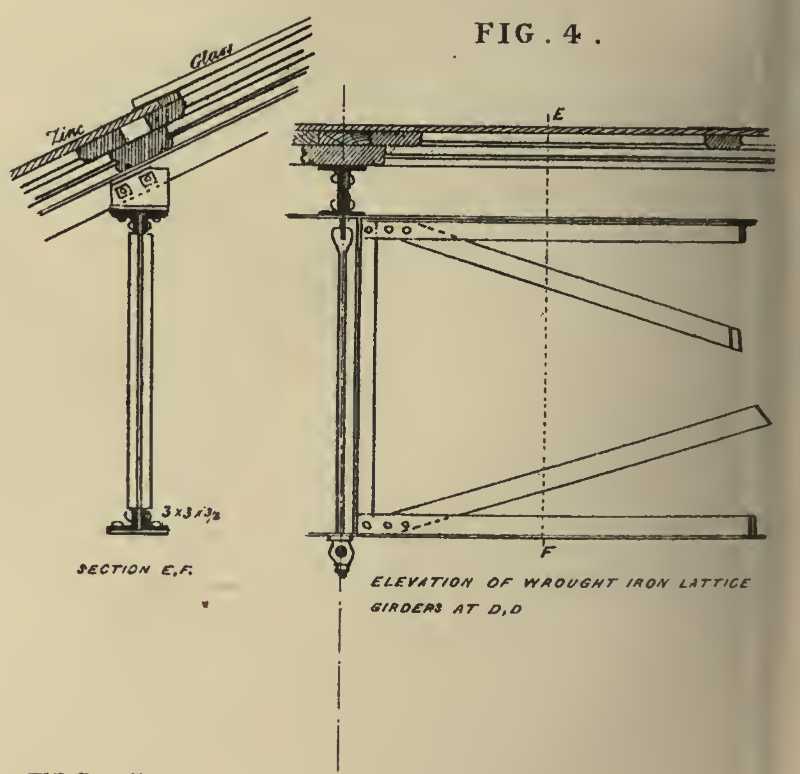
Centimetres 0 10 20 30 40 50 60 70 80 90 100

FIG. 3.



SECTION C.D.

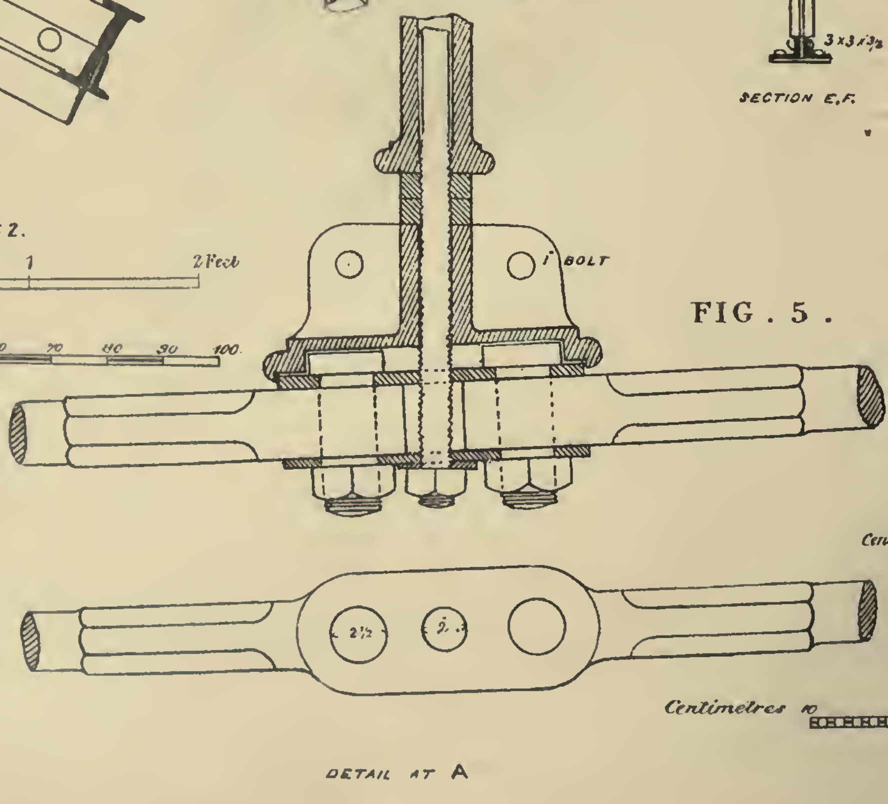
FIG. 4.



SECTION E,F.

ELEVATION OF WROUGHT IRON LATTICE GIRDERS AT D,D

FIG. 5.



DETAIL AT A

SCALE FOR FIGS 4 AND 8.

Inches 12 6 0 1 2 3 4

Centimetres 100 50 0

SCALE FOR FIGS 1.3.5.6.7 AND 9.

Inches 12 9 6 3 0

Centimetres 10 0 10 20 30 40 50 60

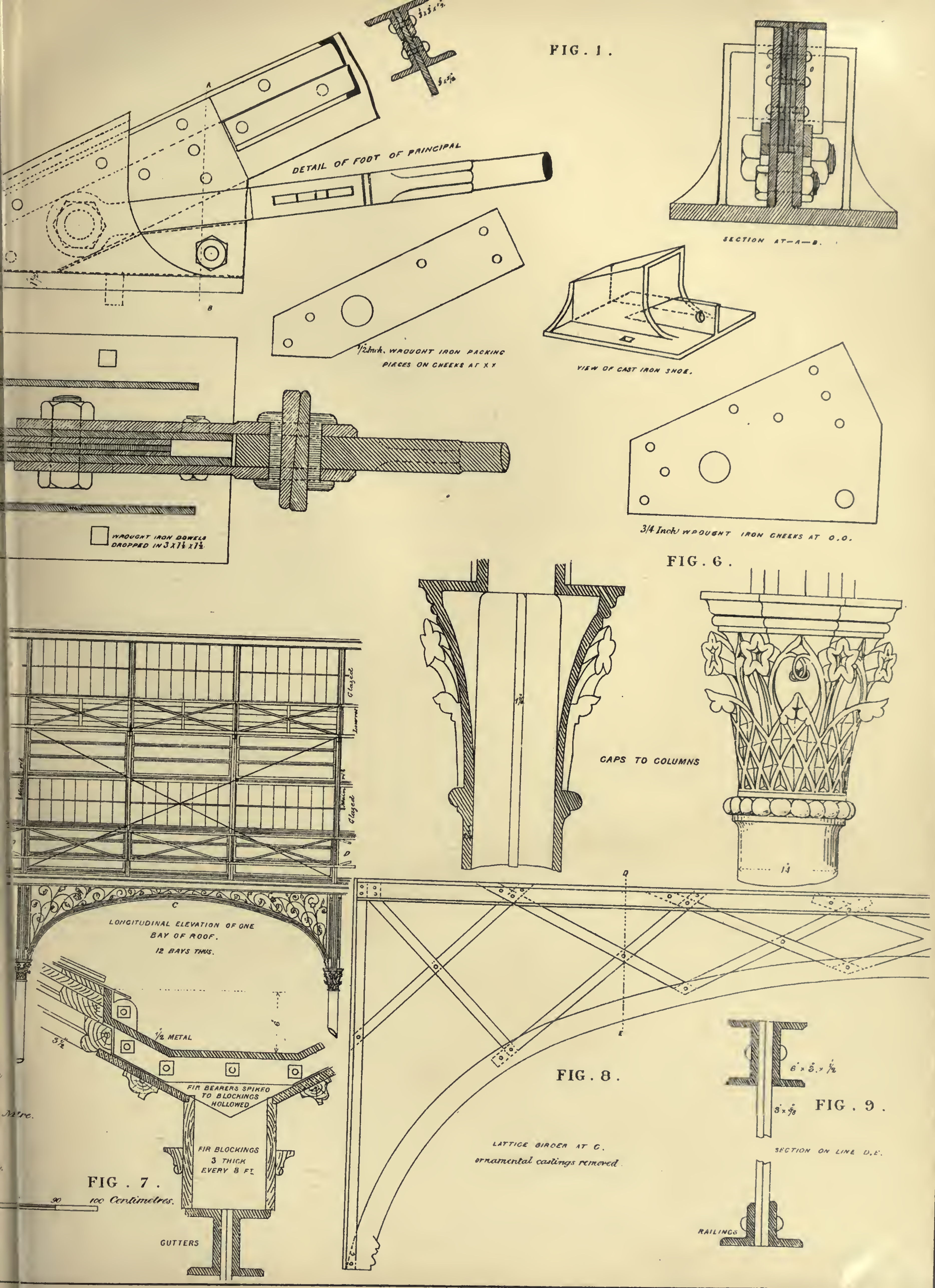
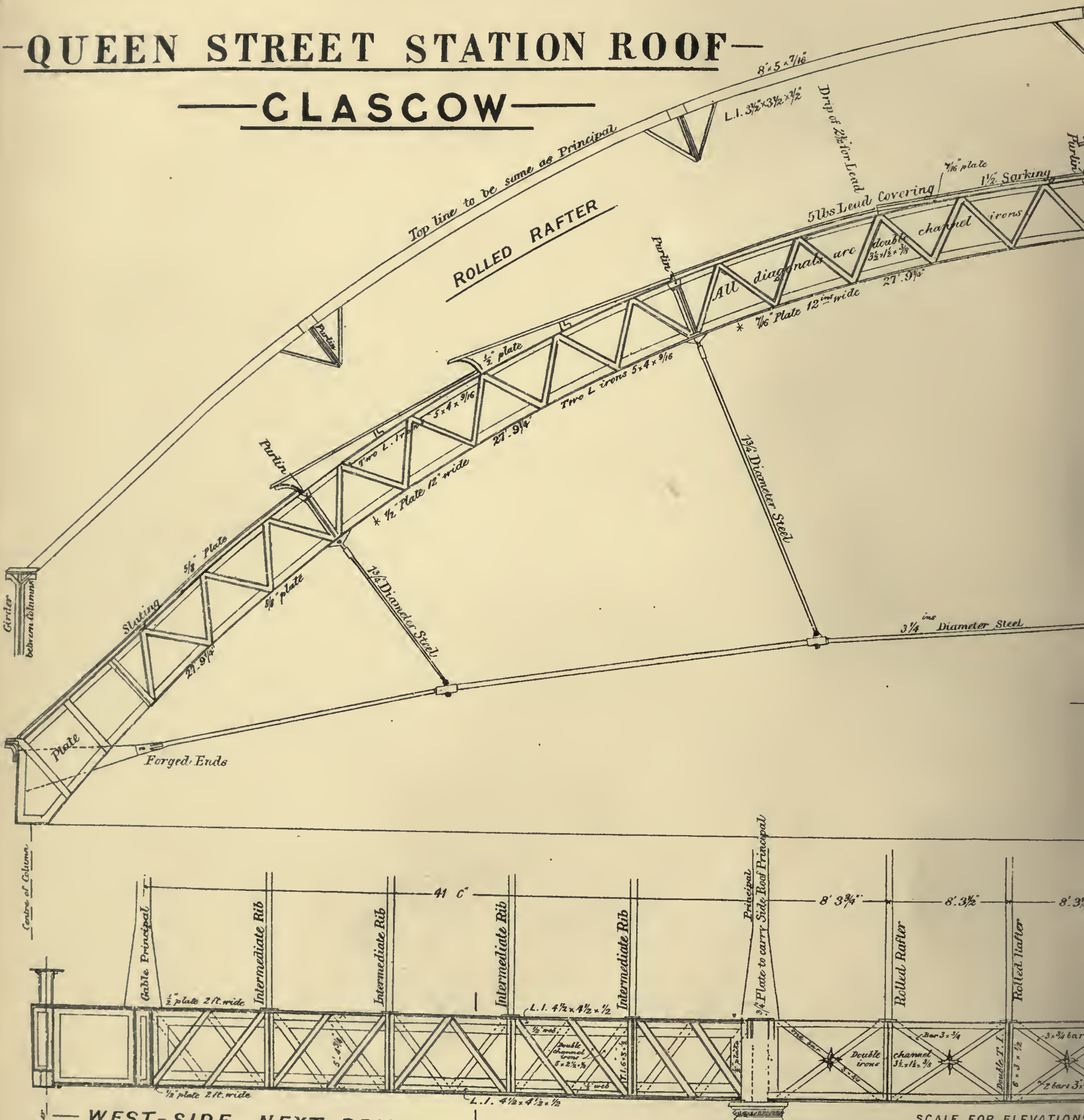


PHOTO-LITHO. SPRAGUE & Co. LONDON.

—QUEEN STREET STATION ROOF—

—GLASGOW—

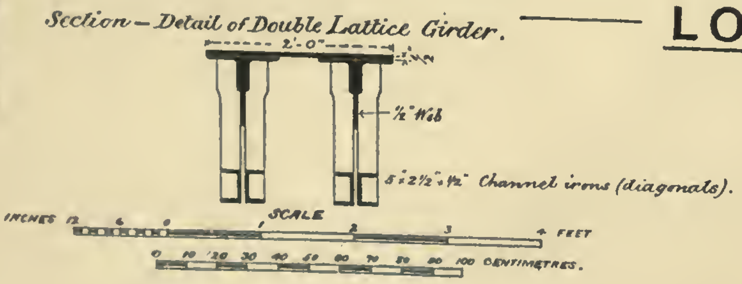


WEST-SIDE-NEXT-BRIDGE

SCALE FOR ELEVATIONS

Feet 5 4 3 2 1 0 5 10

Section — Detail of Double Lattice Girder.

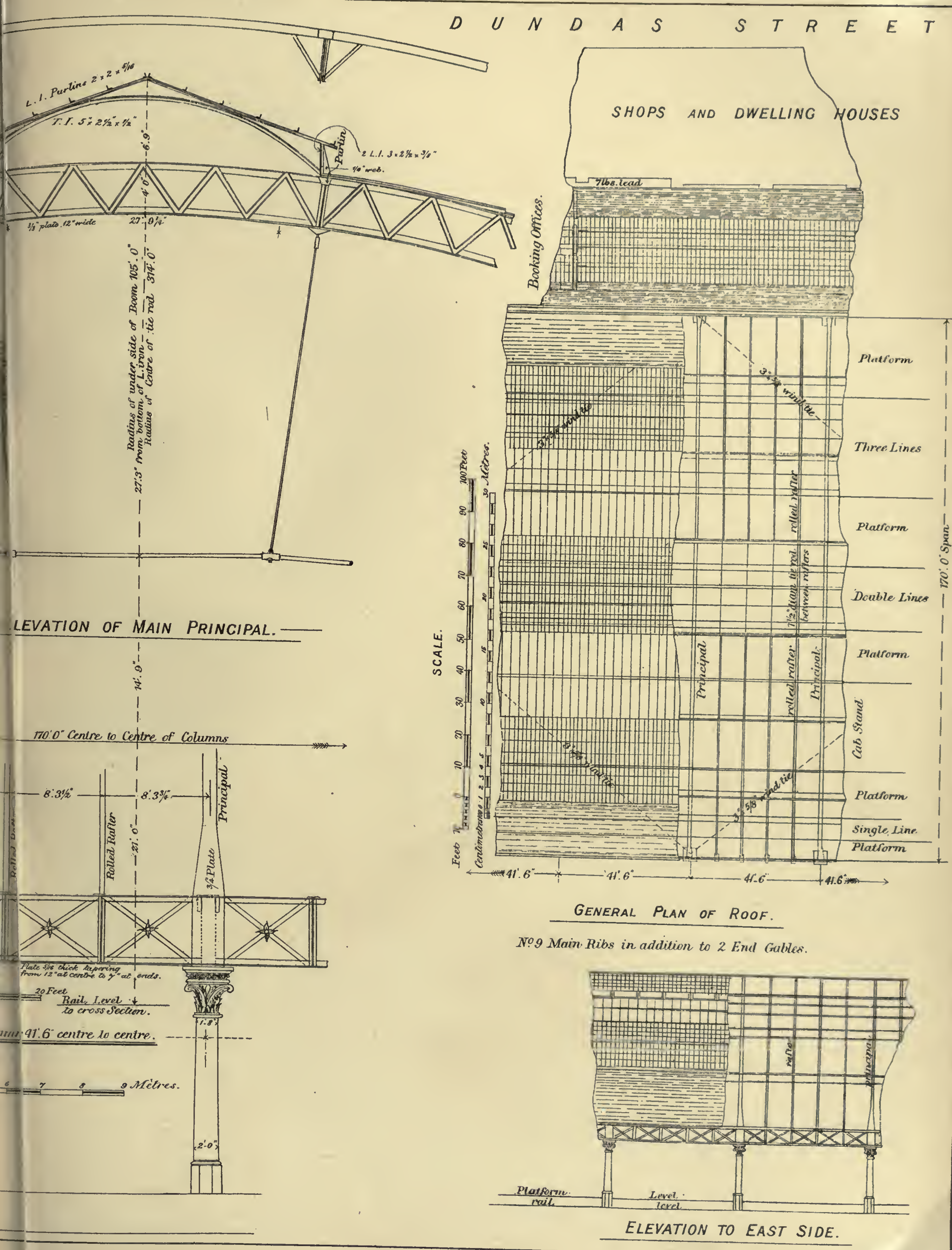


LONGITUDINAL ELEVATION

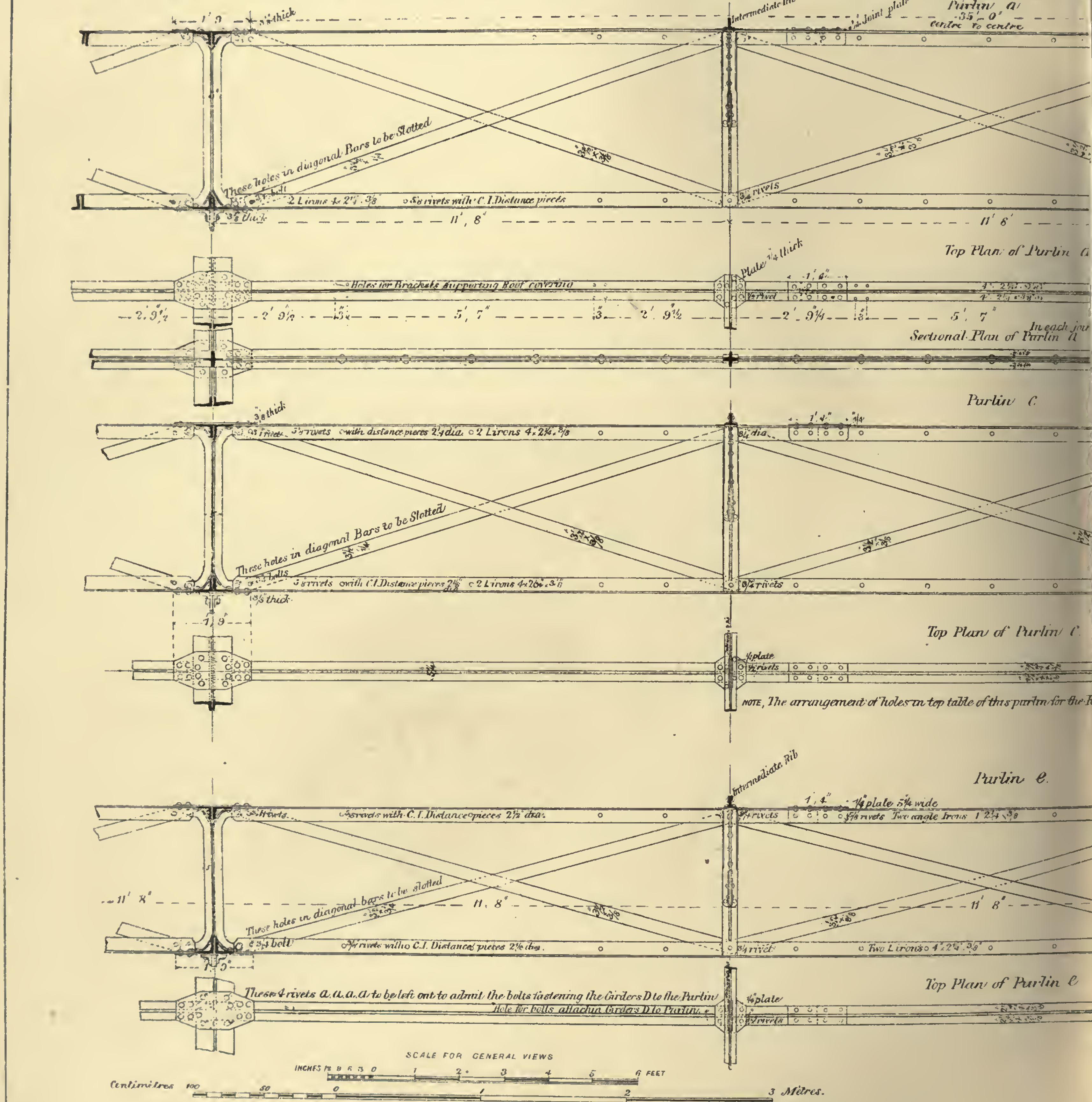
Centimetres 100 0 1 2 3 4 5

Level of Platform

Level of Rails


DUNDAS STREET
SHOPS AND DWELLING HOUSES
7lbs. lead
Booking Offices.
L. I. Purlins 2 x 2 x 5/16
T. I. 5 x 2½ x ½
2 L. I. 3 x 2½ x 3/8
Purlin
⅜" web.
⅜" plate 12" wide
27' 0¼"
6'.9"
4'.0"
Radius of under side of Boom 105'.0"
from bottom of L. iron
Radius of Centre of tie rod 314'.0"
27'.3"
14'.9"
ELEVATION OF MAIN PRINCIPAL.
170'.0" Centre to Centre of Columns
8'.3½"
8'.3½"
Principal
Rolled Rafter
Rolled Rafter
21'.0"
¾ Plate
Plate 5/16 thick tapering from 12" at centre to 7" at ends.
20 Feet
Rail Level to cross Section.
41'.6" centre to centre.
1'.8"
2'.0"
6 7 8 9 Mètres.
SCALE.
Feet
Centimètres
100 Feet
30 Mètres.
3 x ⅜ wind tie
3 x ⅜ wind tie
3 x ⅜ wind tie
3 x 5/8 wind tie
rolled rafter
1½ diam. tie rod between rafters
Principal
rolled rafter
Principal
Platform
Three Lines
Platform
Double Lines
Platform
Cab Stand
Platform
Single Line
Platform
170'.0" Span
41'.6"
41'.6"
41'.6"
41'.6"
GENERAL PLAN OF ROOF.
No. 9 Main Ribs in addition to 2 End Gables.
rafter
principal
Platform rail
Level level
ELEVATION TO EAST SIDE.

VICTORIA STATION PIMLICO L.C. & D.R.



ICE PURLINS

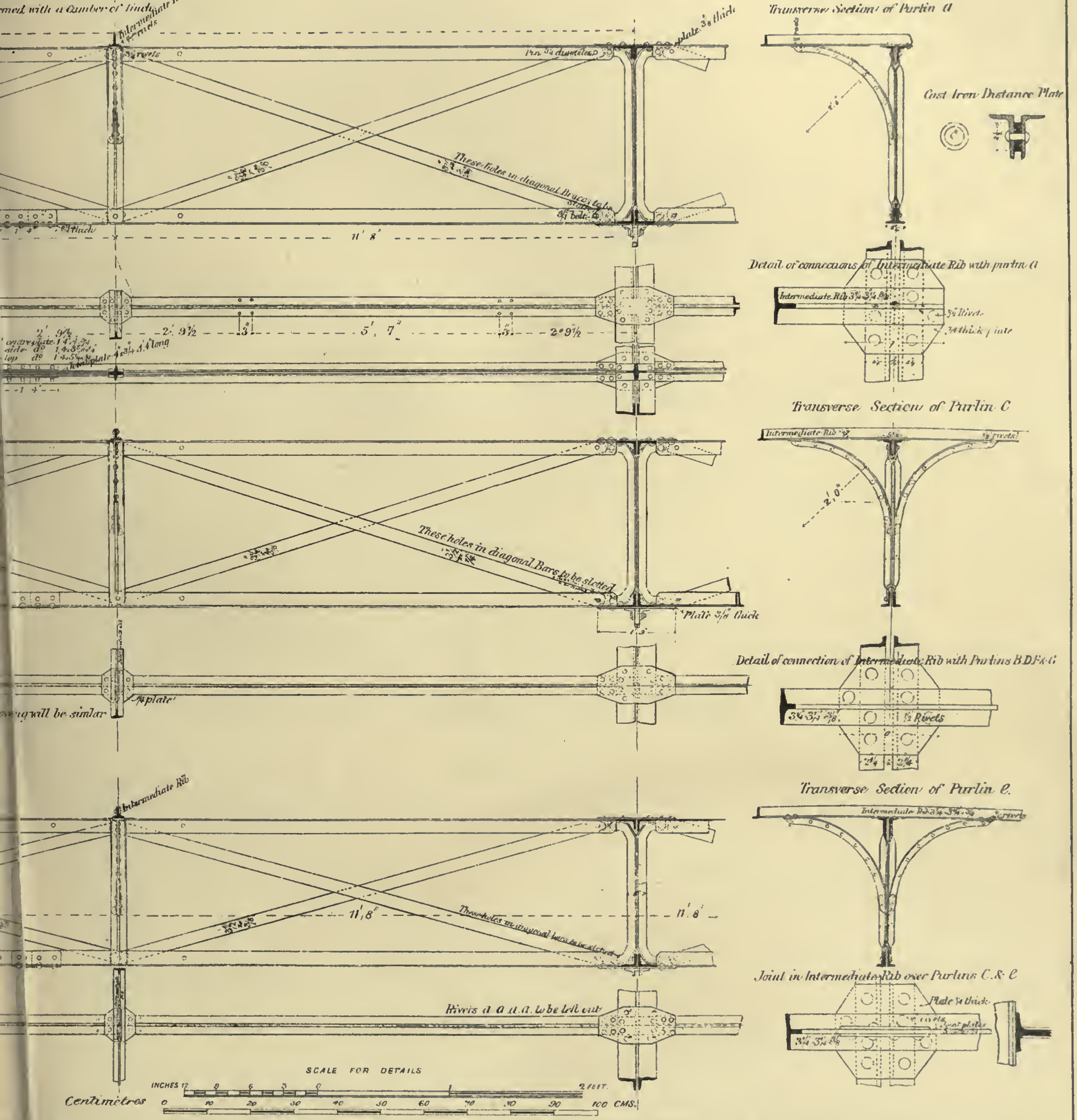
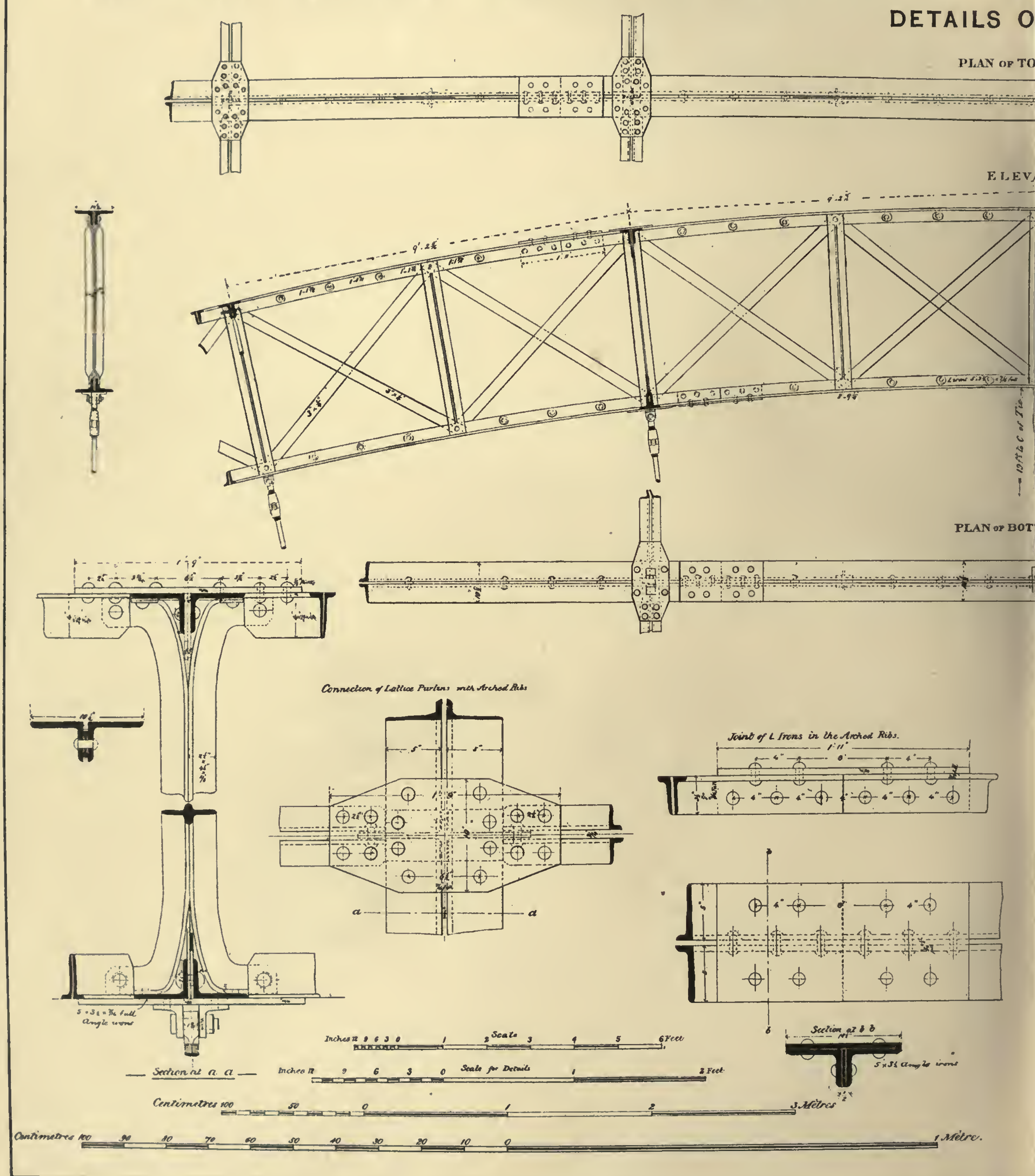
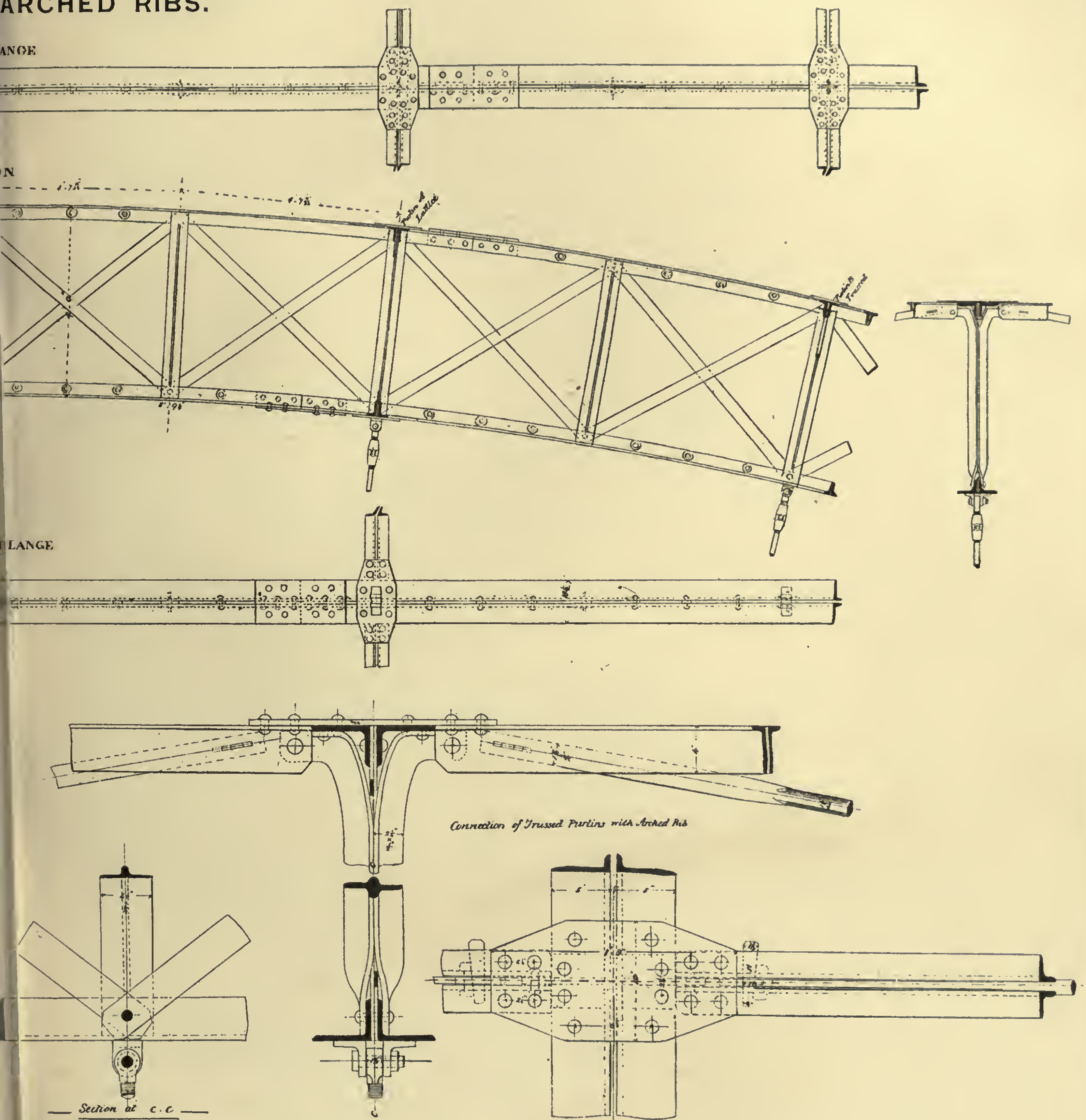


PHOTO-LITHO. SPRAGUE & Co LONDON.

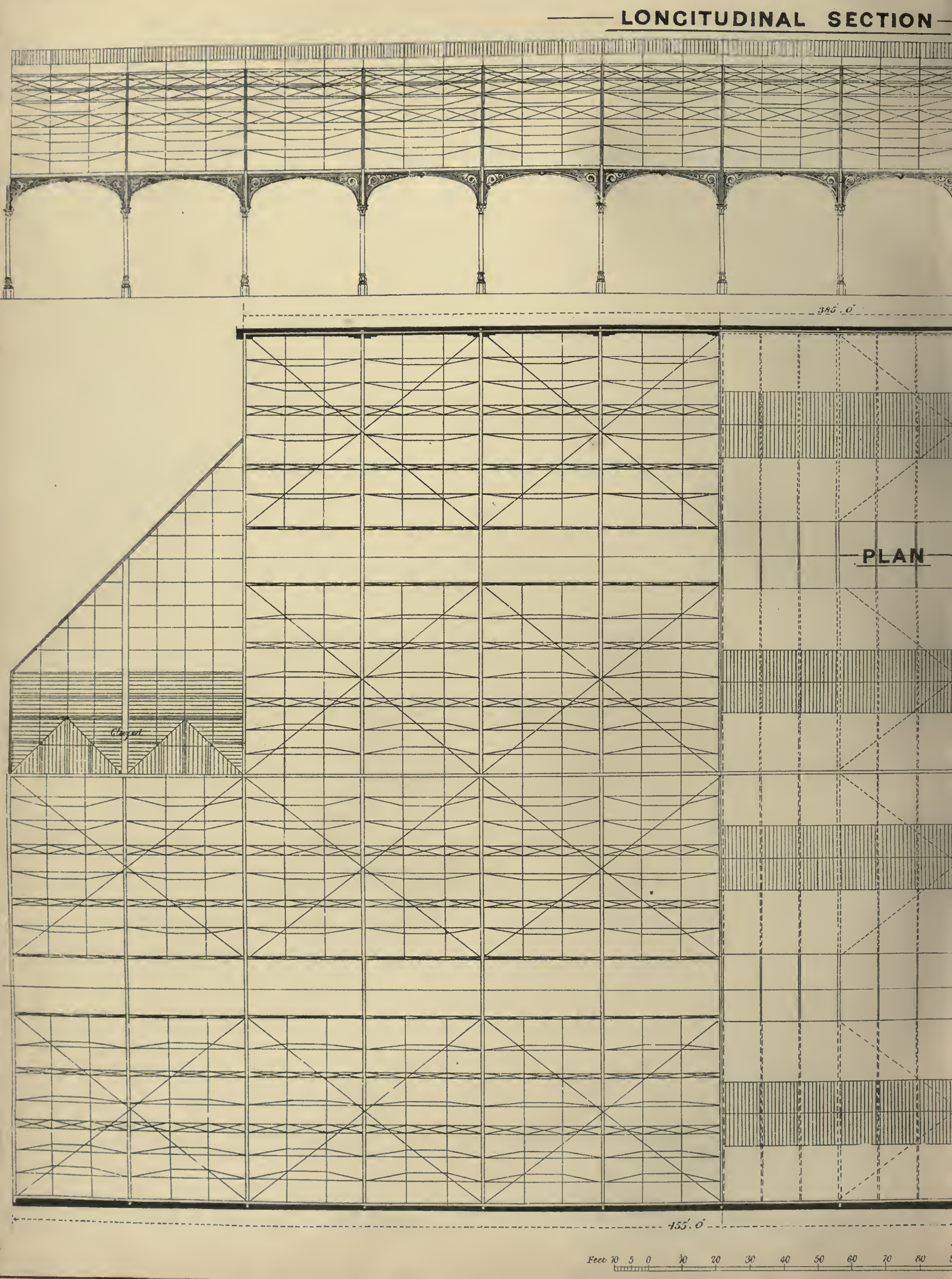
VICTORIA STATION PIMLICO. L.C.&.D.R.

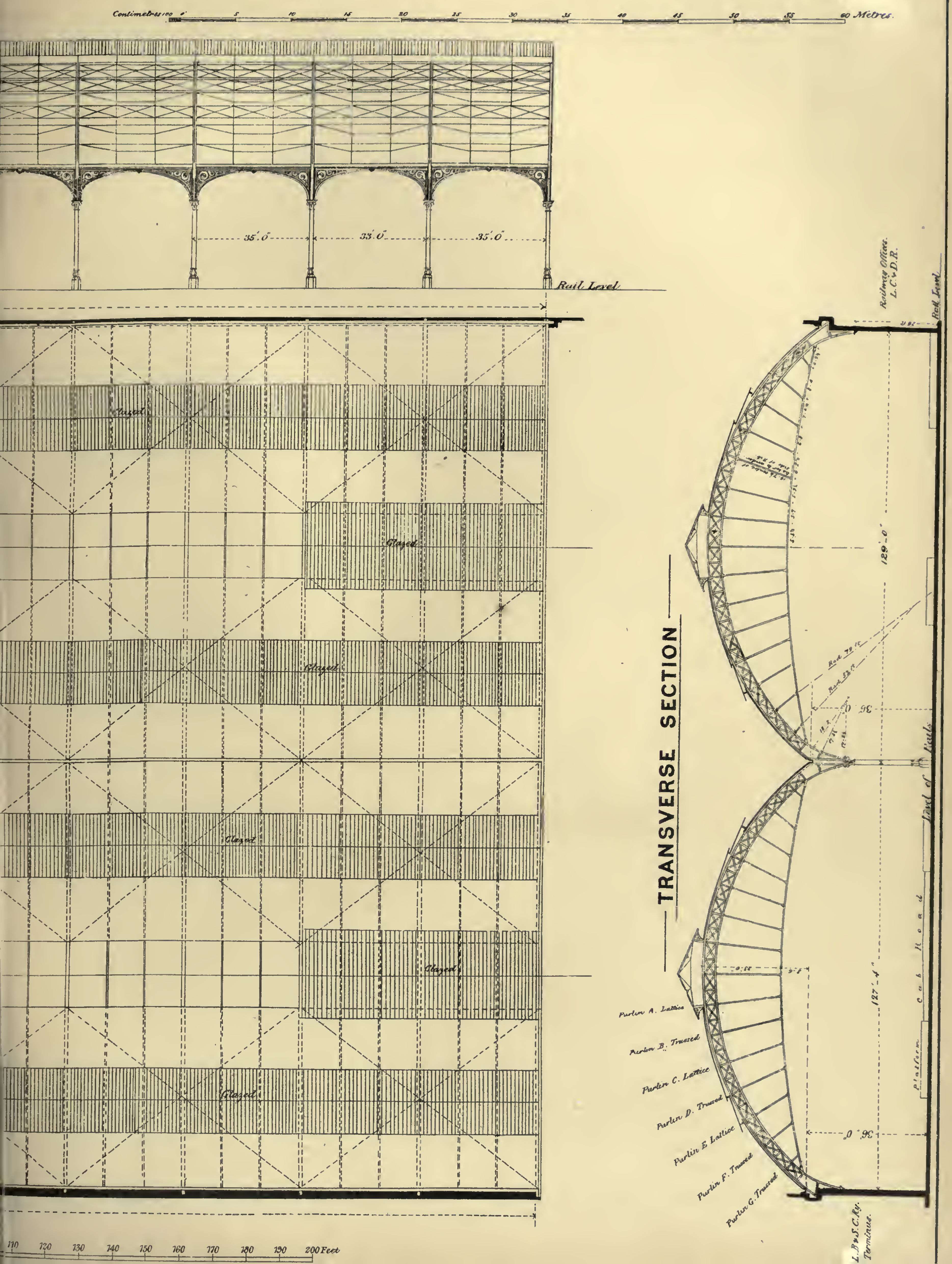


ARCHED RIBS.

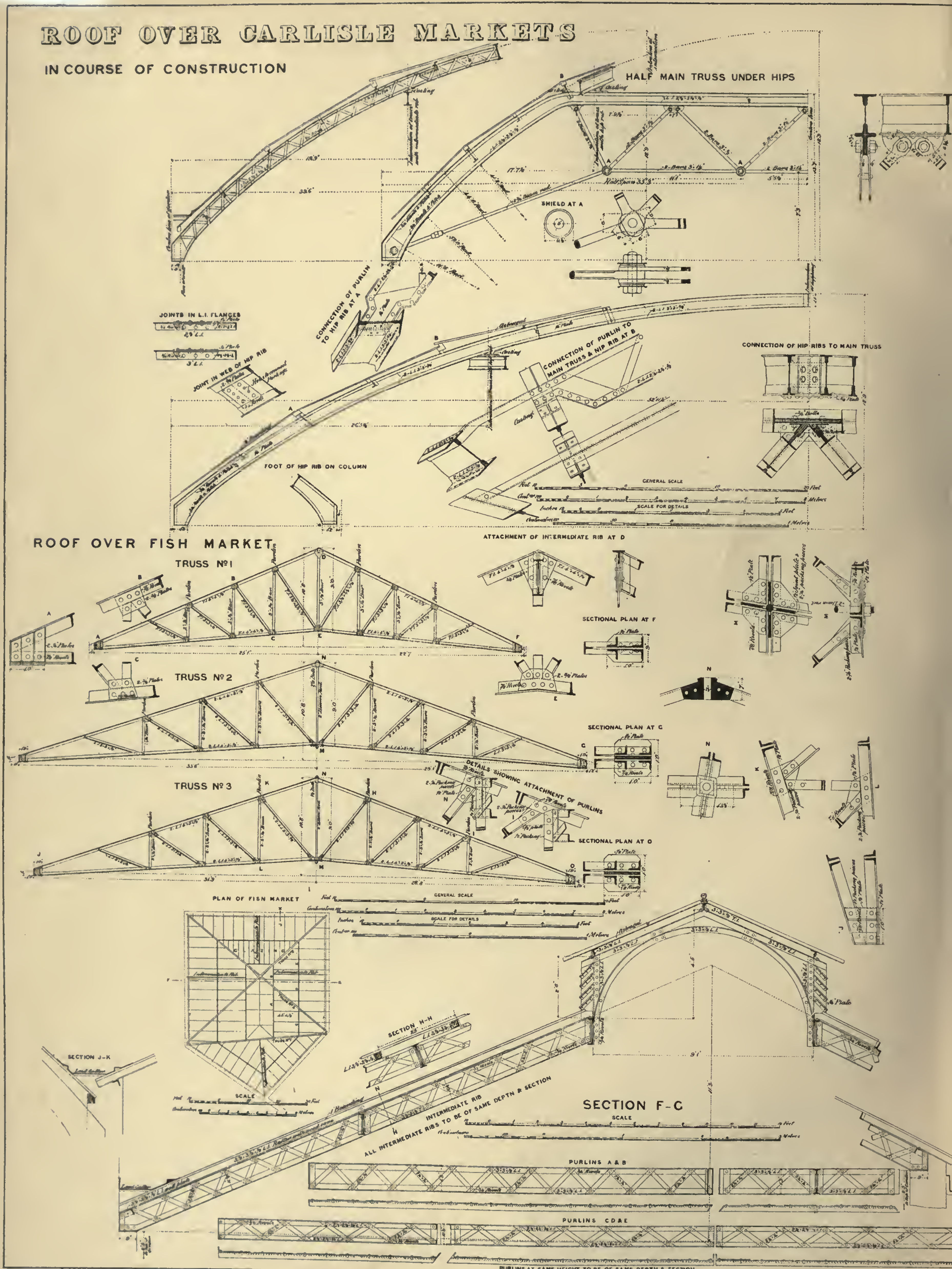

ANGE
ON
LANGE
Connection of Trussed Purlins with Arched Rib
Section at c.c

VICTORIA STATION PIMLICO L. C. & D. R.

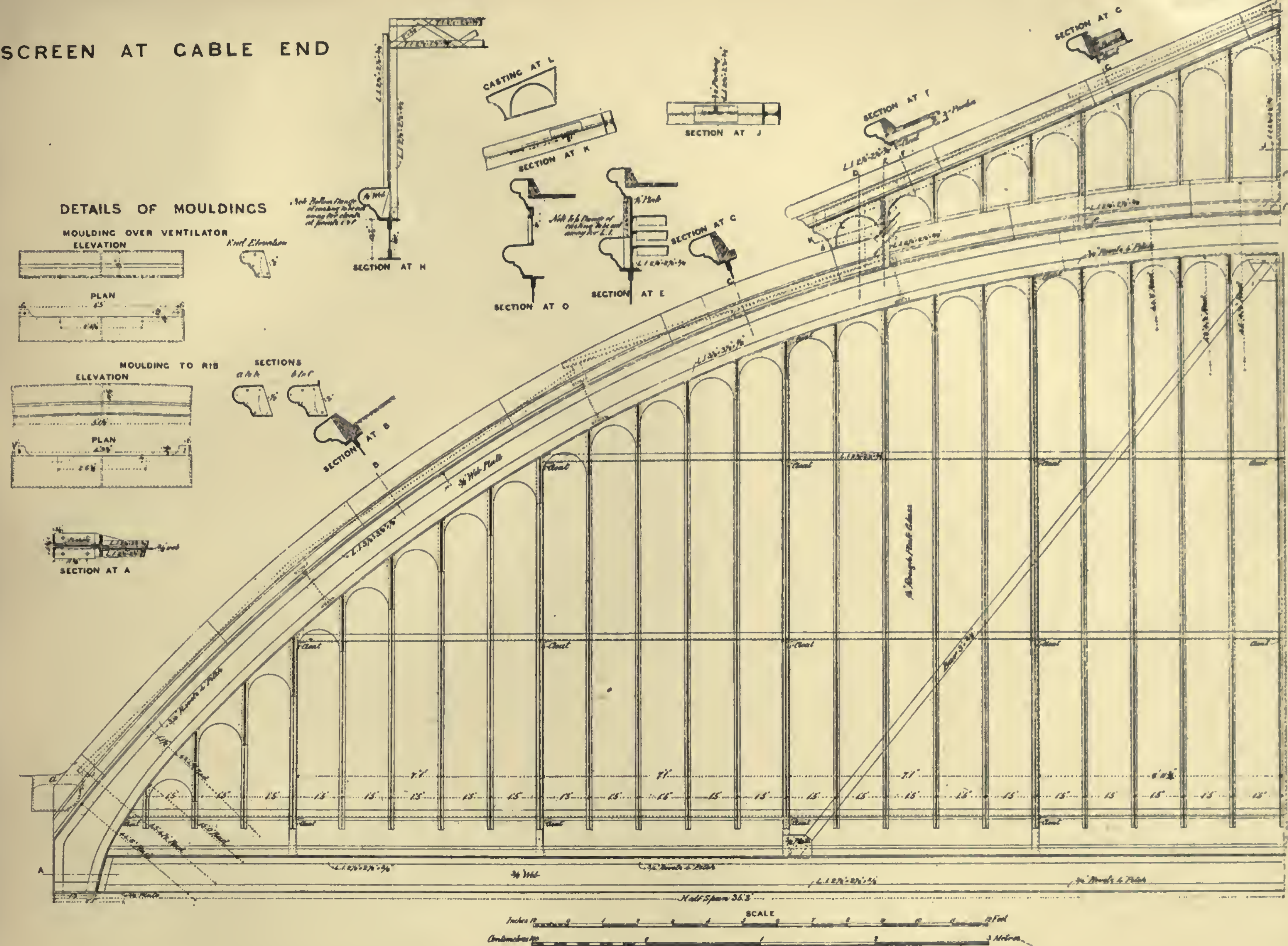




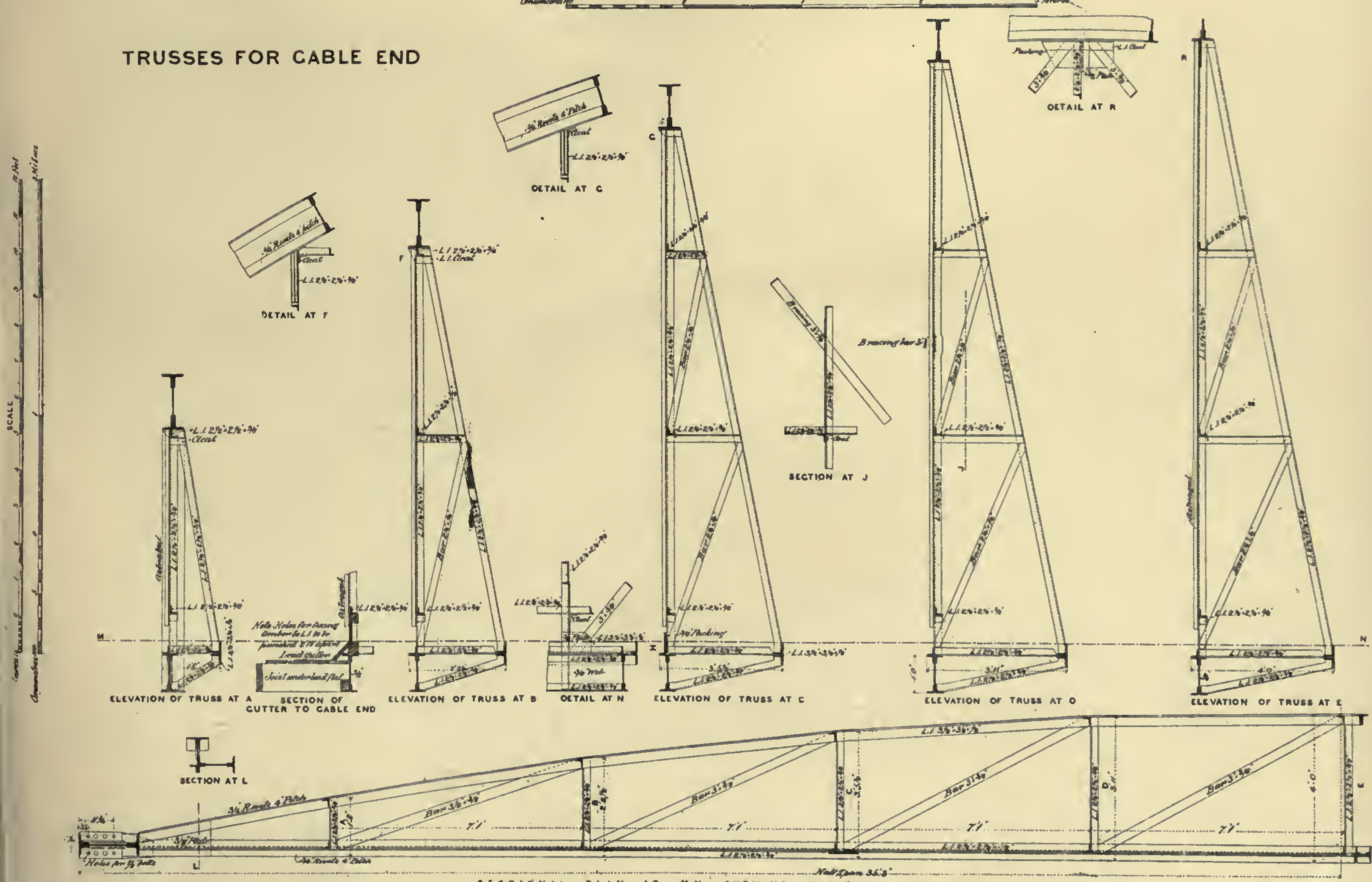
Centimetres 100 0 5 10 15 20 25 30 35 40 45 50 55 60 Metres.
35'.0"
33'.0"
35'.0"
Rail Level
Glazed
Glazed
Glazed
Glazed
Glazed
Glazed
TRANSVERSE SECTION
Railway Offices. L.C.&D.R.
Rail Level
129'.0"
36'.0"
127'.4"
36'.0"
Level of Roads
Cab Road
Platform
Purlin A. Lattice
Purlin B. Trussed
Purlin C. Lattice
Purlin D. Trussed
Purlin E. Lattice
Purlin F. Trussed
Purlin G. Trussed
L.B.&S.C.Ry. Terminus.
110 120 130 140 150 160 170 180 190 200 Feet


ROOF OVER CARLISLE MARKETS
IN COURSE OF CONSTRUCTION
HALF MAIN TRUSS UNDER HIPS
SHIELD AT A
CONNECTION OF PURLIN TO HIP RIB AT A
JOINTS IN L.I. FLANGES
JOINT IN WEB OF HIP RIB
CONNECTION OF PURLIN TO MAIN TRUSS & HIP RIB AT B
CONNECTION OF HIP RIBS TO MAIN TRUSS
FOOT OF HIP RIB ON COLUMN
GENERAL SCALE
SCALE FOR DETAILS
ROOF OVER FISH MARKET
TRUSS Nº1
ATTACHMENT OF INTERMEDIATE RIB AT D
SECTIONAL PLAN AT F
TRUSS Nº2
SECTIONAL PLAN AT G
DETAILS SHOWING ATTACHMENT OF PURLINS
TRUSS Nº3
SECTIONAL PLAN AT O
PLAN OF FISH MARKET
GENERAL SCALE
SCALE FOR DETAILS
SECTION H-H
SECTION J-K
SCALE
INTERMEDIATE RIB
ALL INTERMEDIATE RIBS TO BE OF SAME DEPTH & SECTION
SECTION F-G
SCALE
PURLINS A & B
PURLINS C D & E
PURLINS AT SAME HEIGHT TO BE OF SAME DEPTH & SECTION

SCREEN AT CABLE END



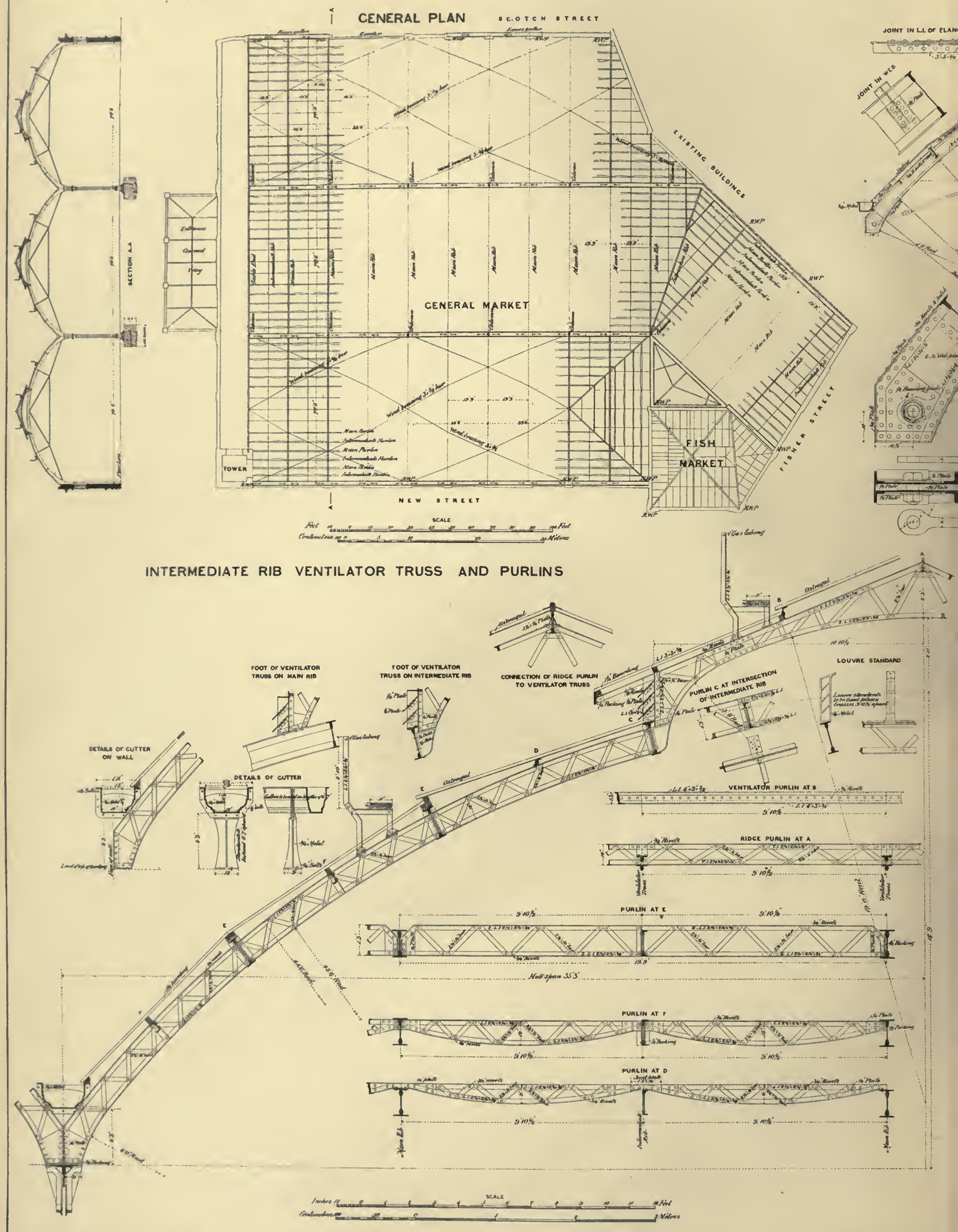
TRUSSES FOR CABLE END



SECTIONAL PLAN AT M-N SHOWING HORIZONTAL TRUSS

PHOTO-LITHO. SPRAGUE & Co. 22, MARTINS LANE, CANNON St. LONDON. E.C.

ROOF OVER CARLISLE MARKETS -IN COURSE OF CONSTRUCTION-



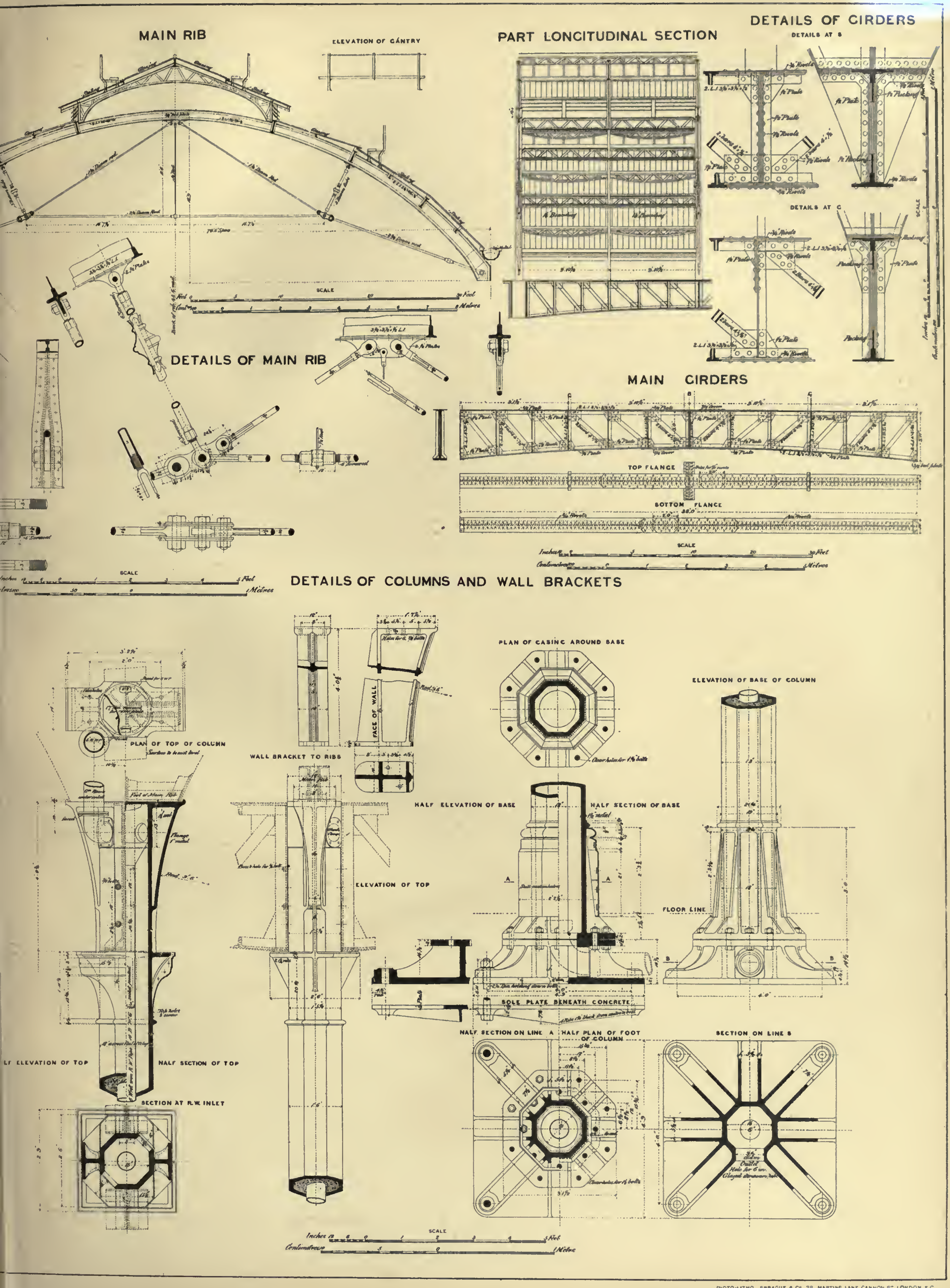
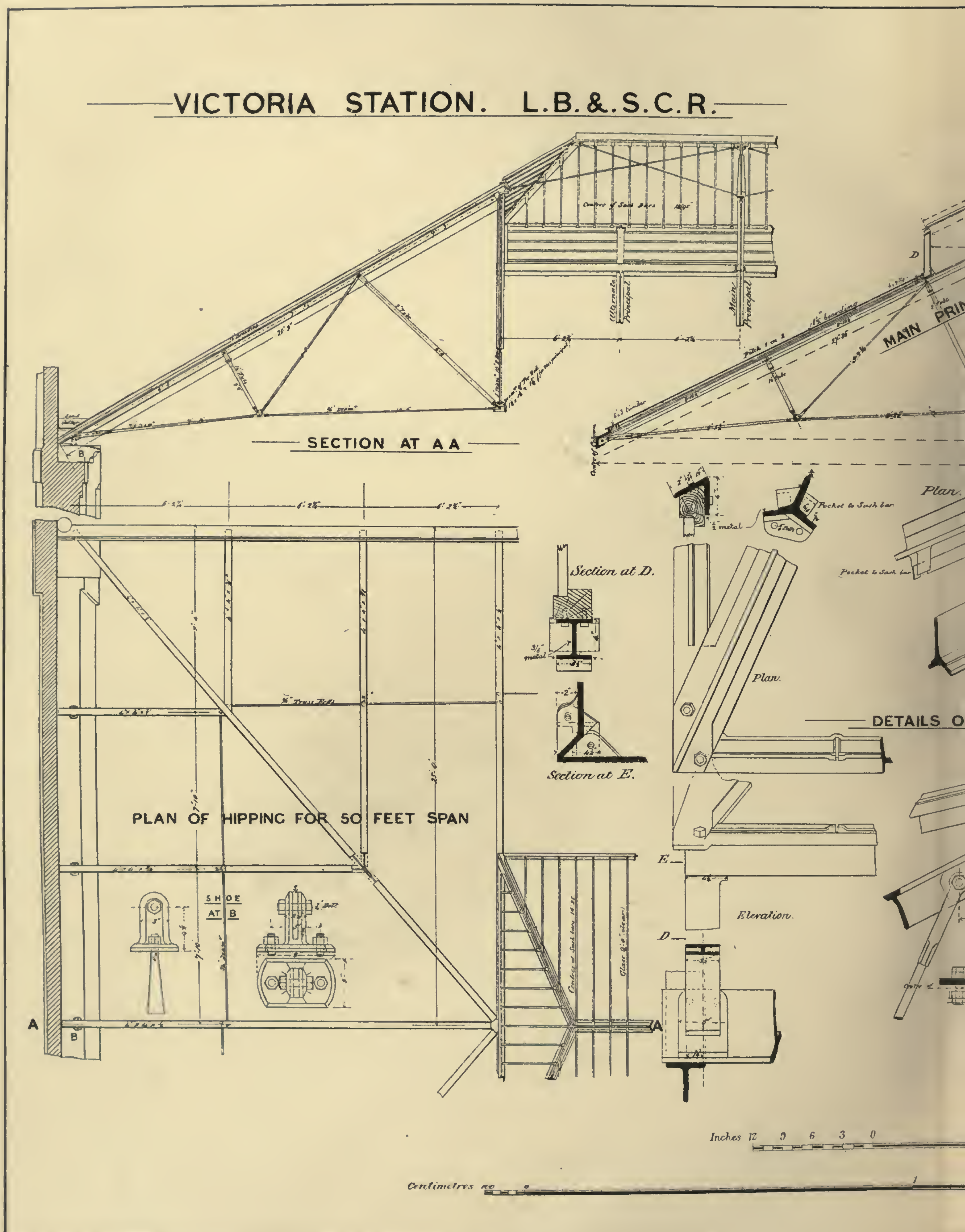


PHOTO-LITHO. SPRAGUE & CO. 22 MARTINS LANE, CANNON ST. LONDON, E.C



VICTORIA STATION. L.B.&.S.C.R.
SECTION AT AA
PLAN OF HIPPING FOR 50 FEET SPAN
SHOE AT B
Section at D.
Section at E.
Plan.
Elevation.
DETAILS O
MAIN PRIN
Pocket to Sash bar
Alternate Principal
Main Principal
Inches 12 9 6 3 0
Centimetres

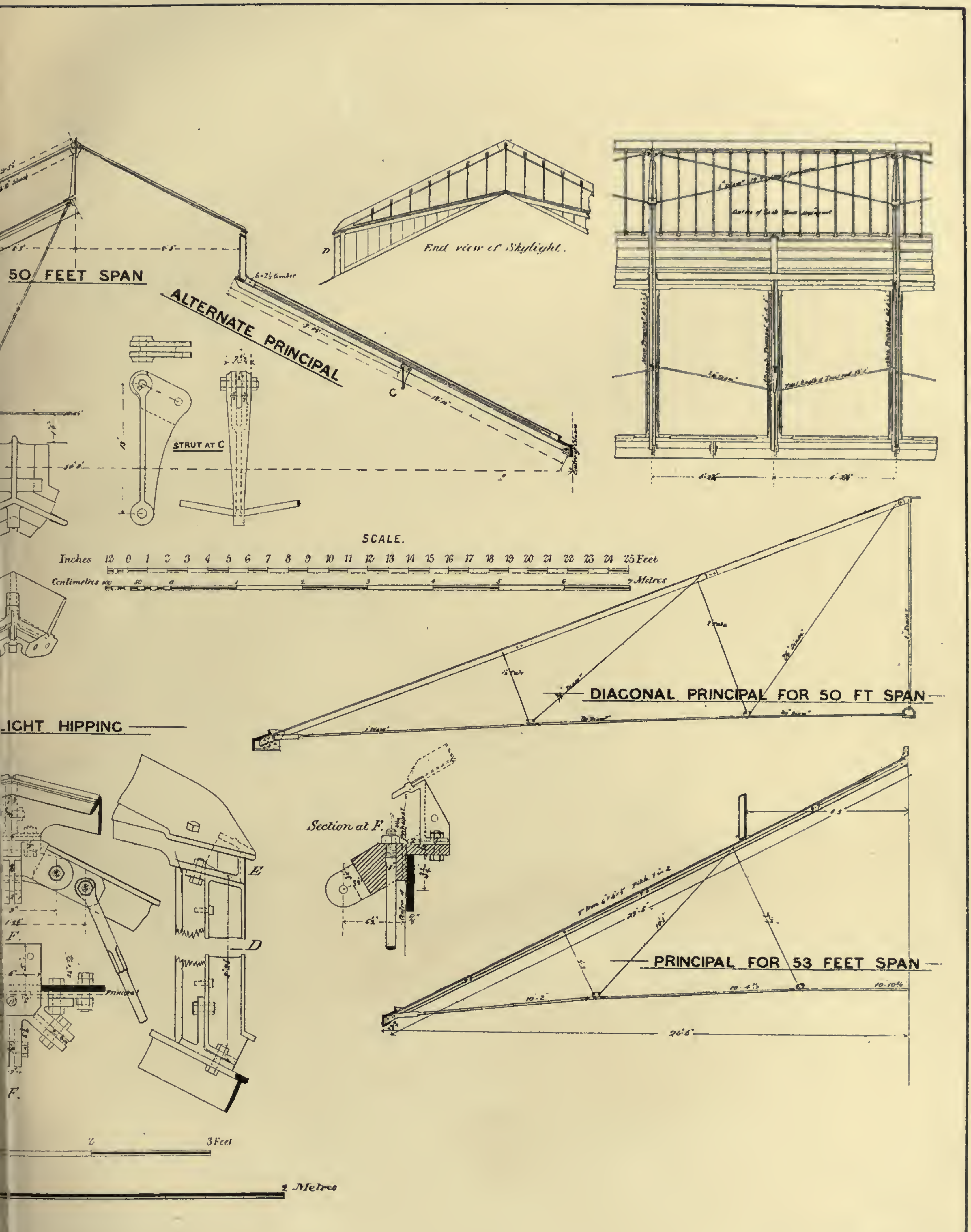
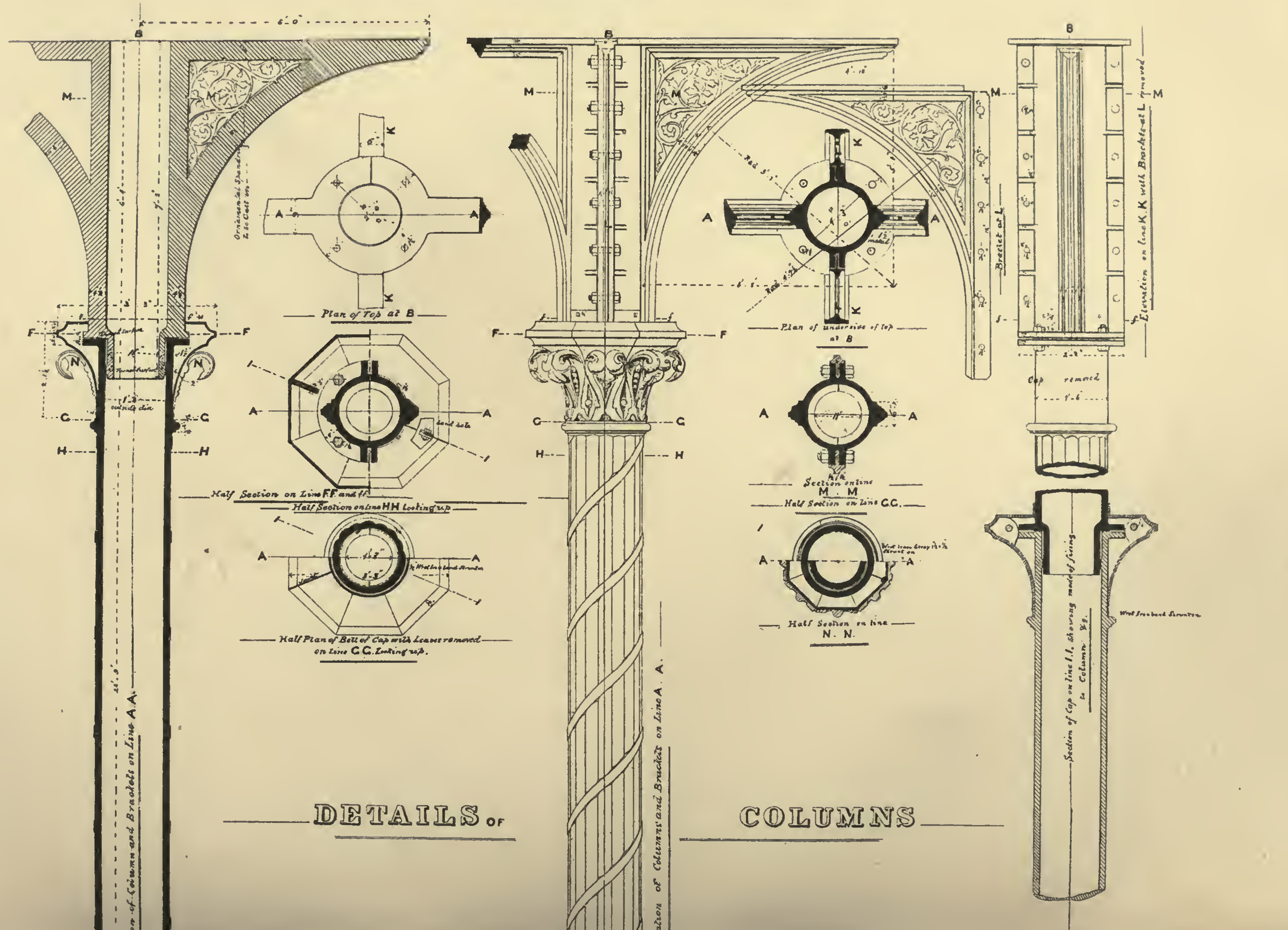


PHOTO-LITHO. SPRAGUE & Co LONDON.

LONDON BRIGHTON & SOUTH COAST RAILWAY

VICTORIA STATION

PIMLICO



DETAILS OF COLUMNS

PLATE No. 26.

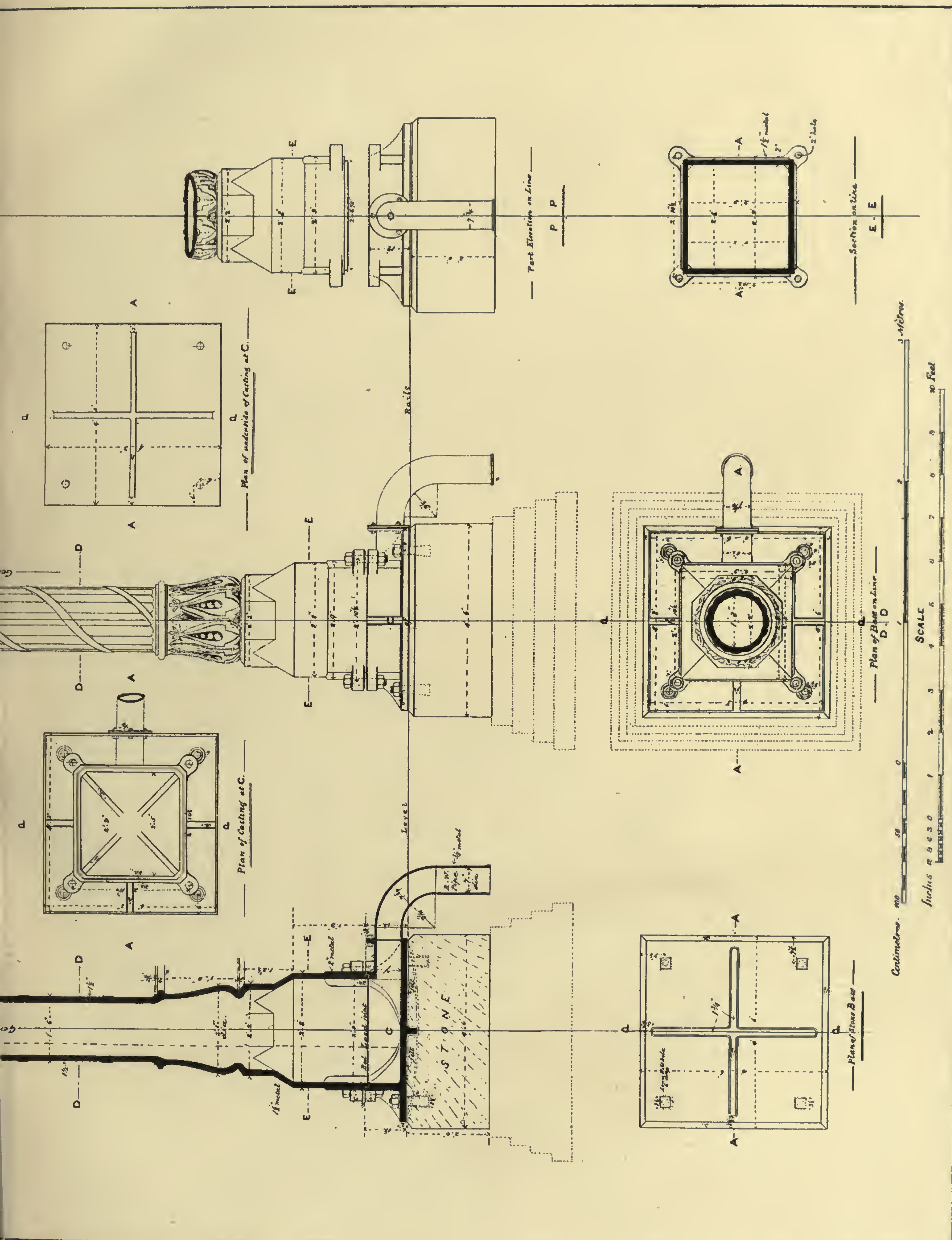
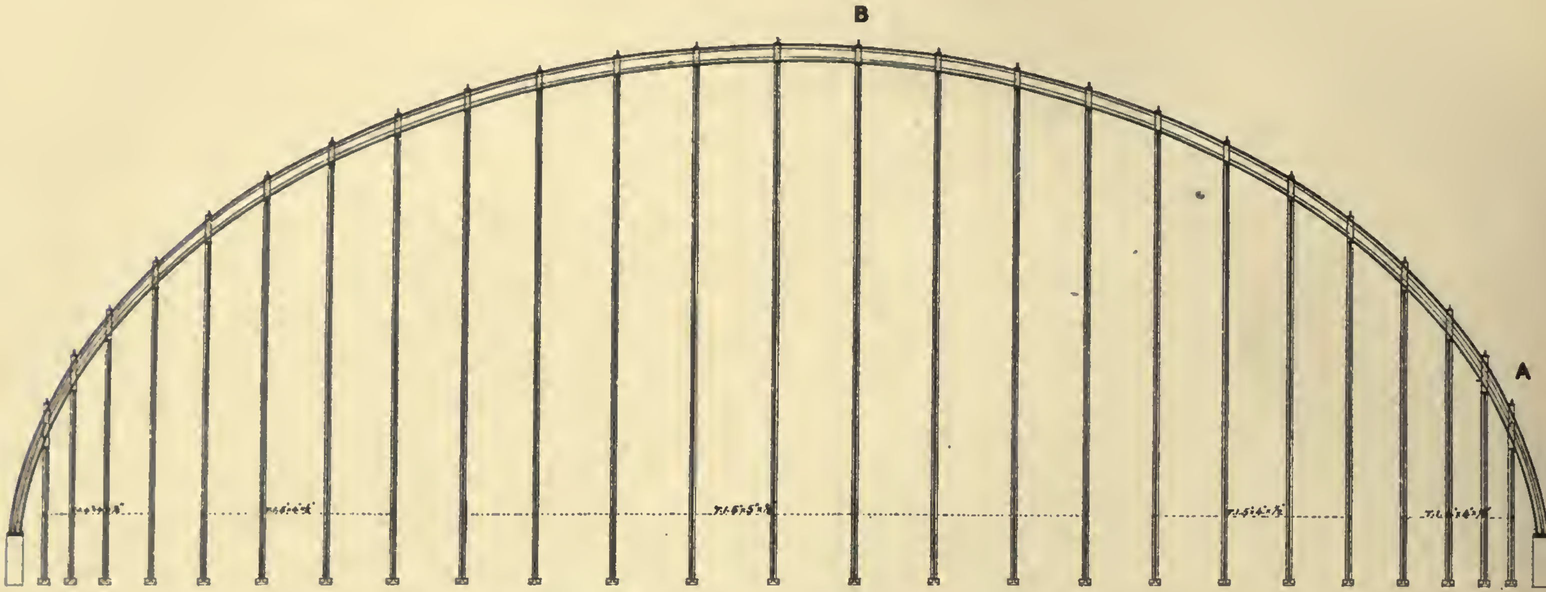
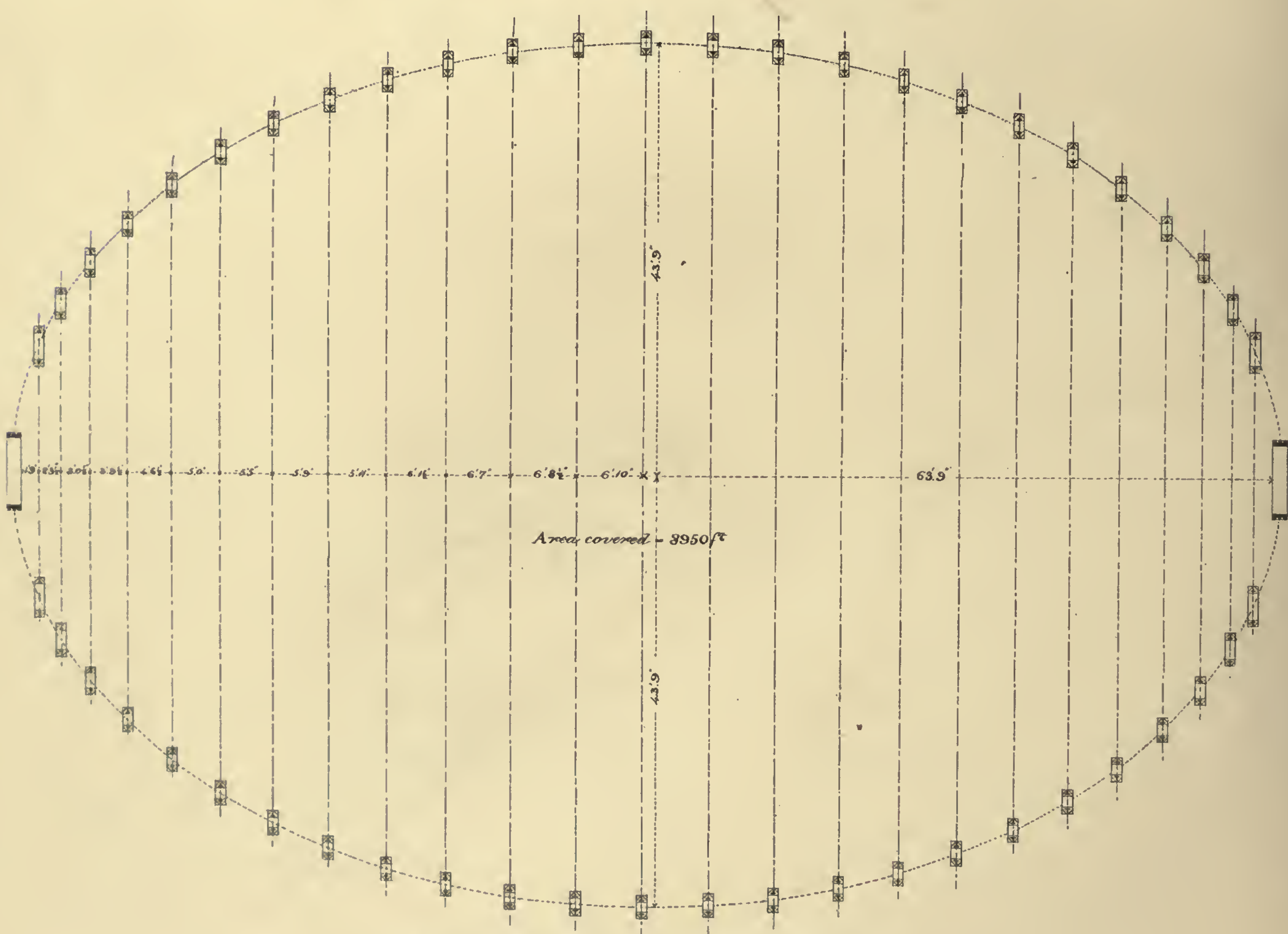


PHOTO-LITHO. SPRAGUE & Co. LONDON.

ROOF OVER CORN EXCHANGE LEEDS

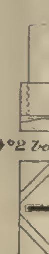


ELEVATION OF LONGITUDINAL RIB



PLAN SHOWING POSITION OF SHOES

The parallel dotted lines indicate centres of transverse ribs



CAS

TRA

These s
to the d

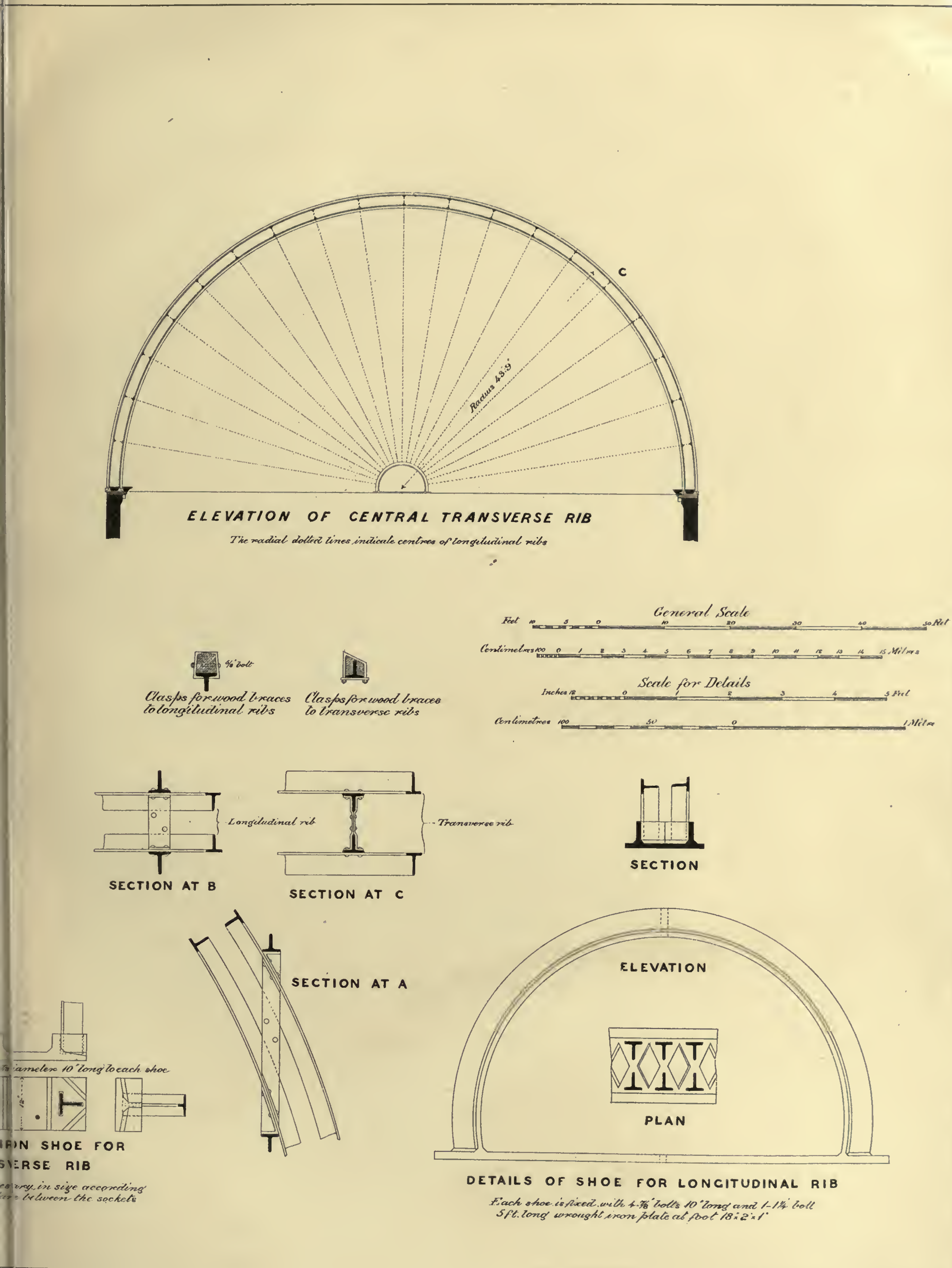
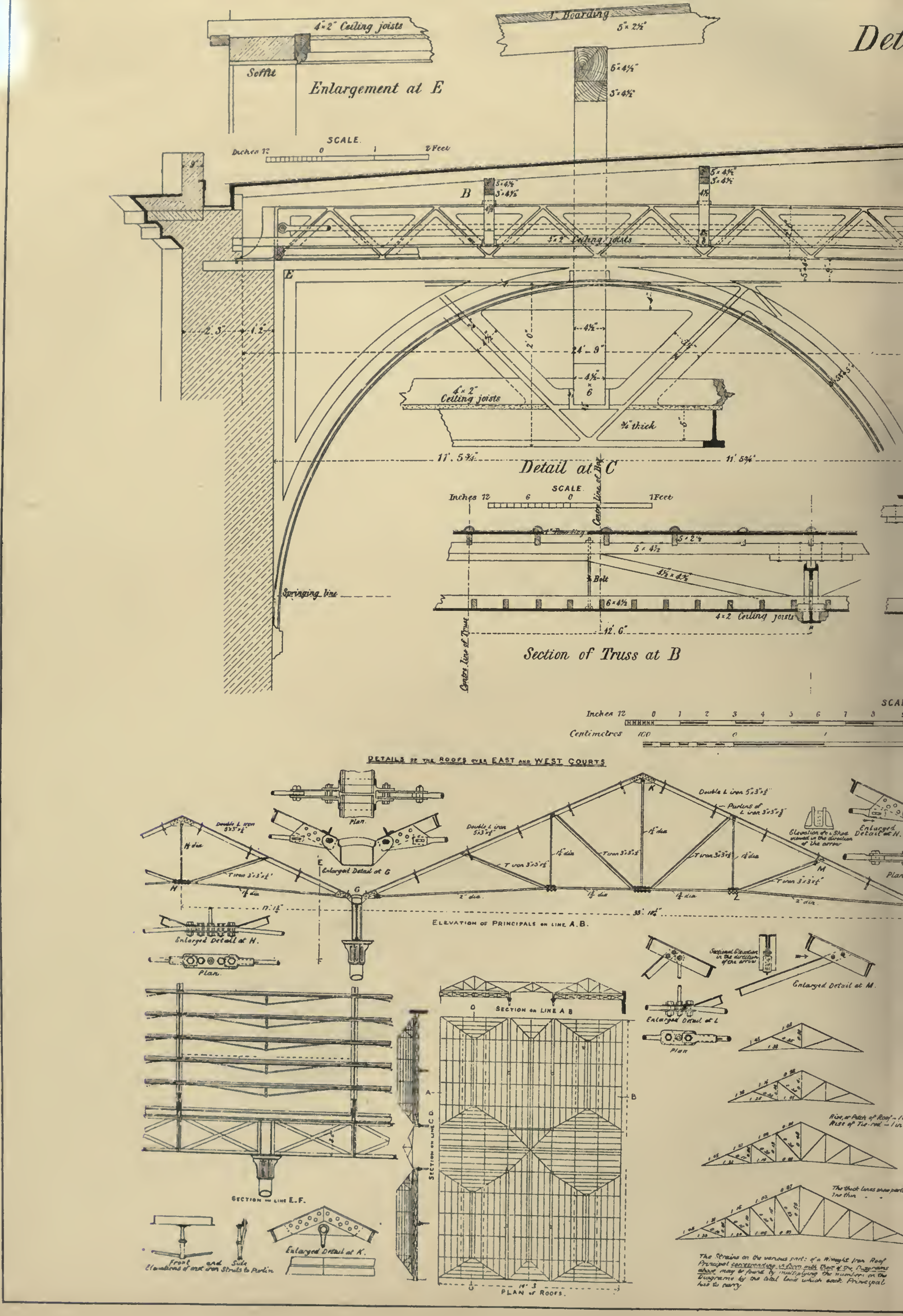
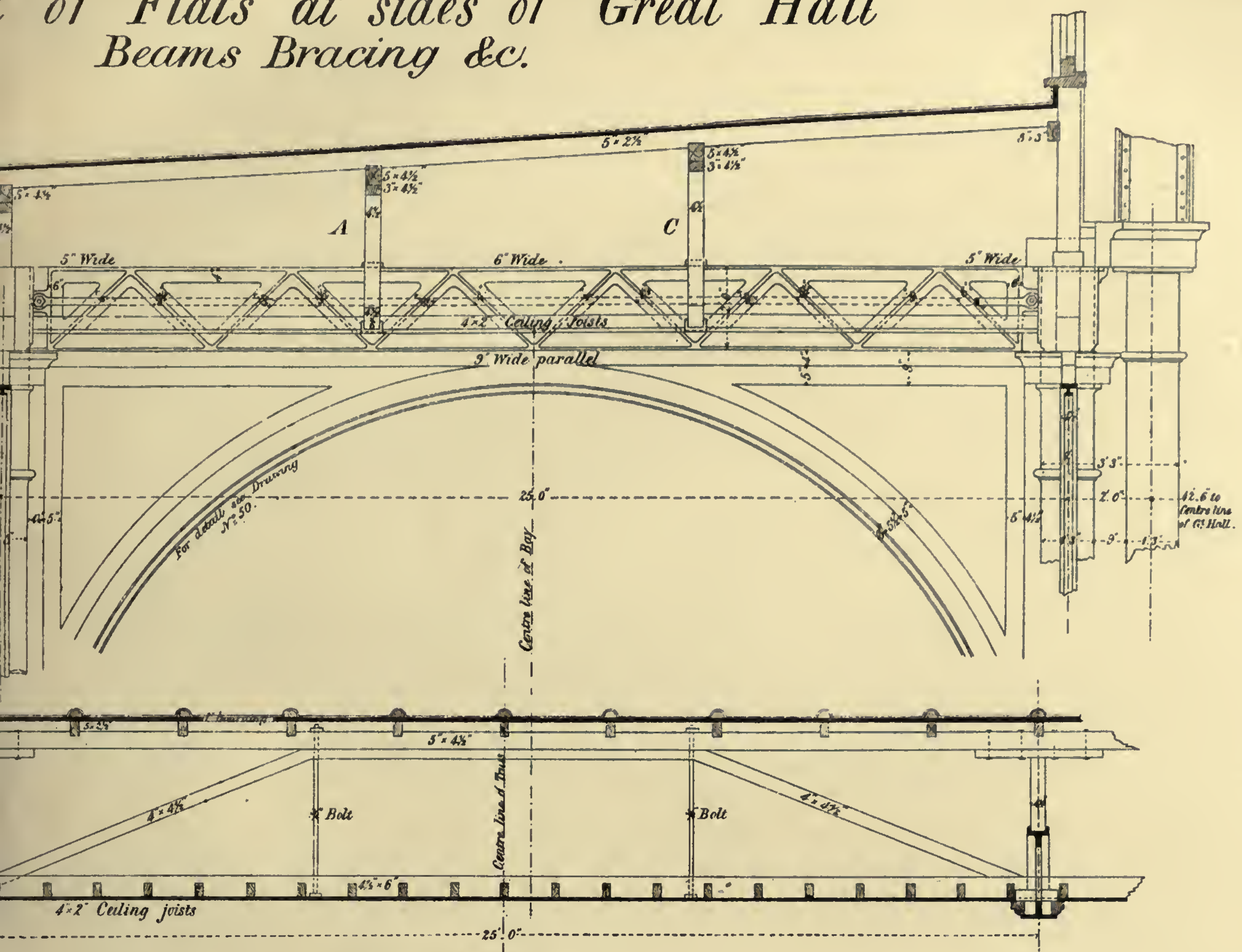


PHOTO-LITHO SPRAGUE & Cº 22 MARTINS LANE, CANNON ST LONDON E.C.

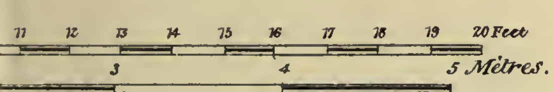

Det
1" Boarding
4"×2" Ceiling joists
Soffit
Enlargement at E
SCALE.
Inches 12 0 1 2 Feet
3"×2" Ceiling joists
Detail at C
SCALE.
Inches 12 6 0 1 Feet
4"×2" Ceiling joists
¾" thick
Springing line
Centre line of Truss
Section of Truss at B
4×2 Ceiling joists
Centimetres
DETAILS OF THE ROOFS OVER EAST AND WEST COURTS
Plan.
Enlarged Detail at G
Enlarged Detail at H.
ELEVATION OF PRINCIPALS ON LINE A.B.
Enlarged Detail at M.
Enlarged Detail at L
SECTION ON LINE A B
SECTION ON LINE E.F.
SECTION ON LINE C D.
Enlarged Detail at K.
Front and Side Elevations of cast iron Struts to Purlin
PLAN OF ROOFS.
The Strains on the various parts of a Wrought Iron Roof Principal corresponding in form with that of the Diagrams above may be found by multiplying the numbers on the Diagrams by the total load which each Principal has to carry.

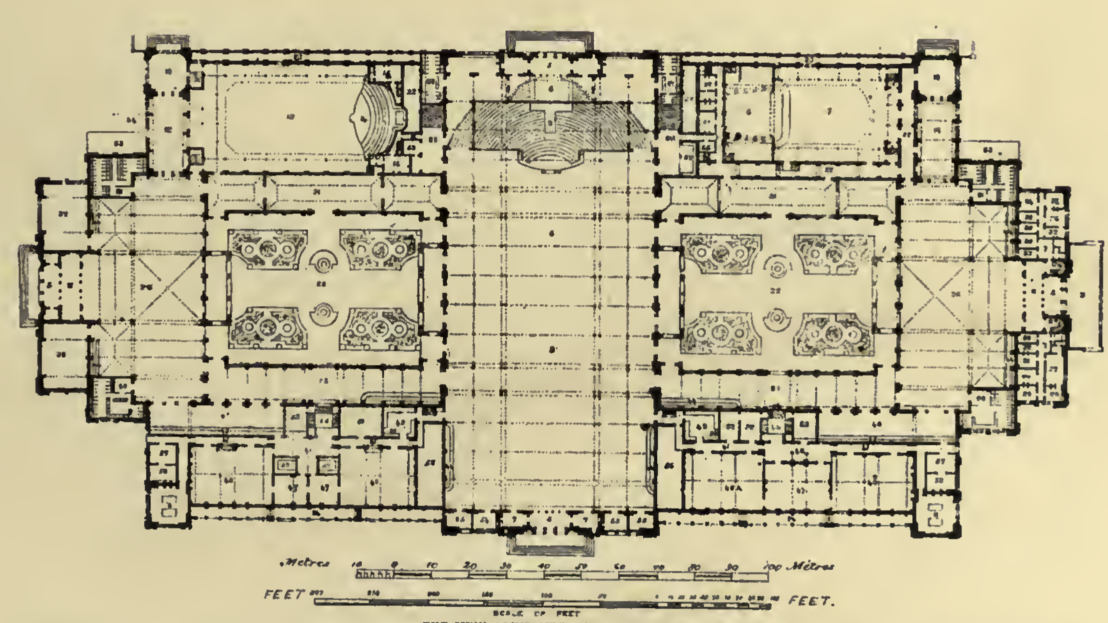
LEXANDRA PALACE

l of Flats at sides of Great Hall
Beams Bracing &c.



Section of Truss at A





THE NEW ALEXANDRA PALACE.—*Plan.*

1. South terrace.
2. North terrace.
3. East (inclosed carriage) entrance.
4. West entrance.
5. Outside lobby.
6. Inside lobby.
7. Lobby.
8. Great central hall, [illegible] ft. by [illegible] ft. 6 in.
9. Great orchestra: organ over inside lobby.
10. Tower.
11. Billiard room.
12. Concert-room corridor.
13. Concert-room, [illegible] ft. by [illegible] ft. 7 in.
14. Orchestra.
15. Artists' room.
16. Theatre corridor.
17. Theatre, 104 ft. 6 in. by [illegible] ft. 6 in.
18. Stage, [illegible] ft. deep.
19. Artists' entrance.
20. Artists' retiring-rooms.
21. Exhibition gallery, [illegible] ft. wide each.
22. Open court.
23. Open area.
24. Open colonnade.
25. Glazed corridor, 30 ft. wide each.
26. Conservatory, 201 ft. by 104 ft. 4 in. each.
27. Board-room.
28. Secretary's office.
29. Secretary's clerks.
30. Clerks' office.
31. Board's refreshment-room.
32. Waiting-room.
33. Porter.
34. First superintendent.
35. Second superintendent.
36. Manager's room.
37. Manager's clerks.
38. Library and reading-room, [illegible] ft. by [illegible] ft.
39. Theatre for special purposes, [illegible] ft. by [illegible] ft.
40. First-class banquet-room, [illegible] ft. by [illegible] ft. and [illegible] 6 by [illegible] ft.
40a. First-class coffee-room, [illegible] ft. by [illegible] 6.
40b. Grills and cold meats room, 70 ft. by [illegible] ft.
41. Serving passage.
42. Refreshment-bar.
43. Buffet.
44. Refreshment-buffet.
45. Entrance.
46. Vestibule.
47. Anteroom.
48. Tea and coffee bar.
49. Serving room.
50. Lift. 51. Staff room.
52. Messrs. Bertram and Roberts' offices.
53. Wine bar.
54. Telegraph and post-office.
55. Office. 56. Glazed court.
57. Wash-up. 58. Glass.
59. Hats, coats, &c.
60. Ladies' retiring-room.
61. Gentlemen's retiring-room.
62. From railway platform.
63. Gateway incline.
64. Corridor to proposed aquarium.
65. Stores.

PHOTO-LITHO, SPRAGUE & Co. LONDON.

PLATE Nº 11.

"INK PHOTO" SPRAGUE & Cº LONDON.

CORN EXCHANGE, LEEDS.

Manchester Central Station.

INK-PHOTO, SPRAGUE & Co. LONDON.